Technology Education to Engineering: A Good Move?

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Abstract

Recent curriculum changes in the educational system of Australia have resulted in allowing optional Engineering course work to count for university entrance for students choosing to apply to a university. In other educational systems, Engineering is playing an increasingly important role, either as a stand-alone subject or as part of an integrated approach to Science, Mathematics, and Technology. These developments raise questions about the relationship between Engineering and Technology education, some of which are explored in this article.

Introduction

Curriculum agendas that include a proposed link between Technology and other curriculum areas rarely seem to favor Technology. When Science and Technology are offered in primary schools, science is prioritized, and consequently technology is not delivered well (Williams, 2001). This is a function of both primary school facilities and primary teacher training. Science and Technology offerings in secondary schools tend to be quite academic rather than practical (Williams, 1996). Numerous Science, Technology, and Mathematics (STM, SMT, or TSM) projects that have been developed around the world produce interestingly integrated curriculum ideas and projects, but these have rarely translated into embedded state or national curriculum approaches. This is partly because the school and curriculum emphasis on Science, Technology, and Mathematics is not equivalent across these areas. Even the earliest integrated approaches involving these subjects promoted reform in Science and Mathematics (LaPorte & Sanders, 1993) rather than the goals of Technology. Recently, Engineering, has been brought into the mix as a number of Science, Technology, Engineering and Math (STEM) projects have been developed, most significantly, in terms of numbers and influence, both in the United Kingdom and the United States. Again, the agenda for this type of amalgamation is not being driven by a desire to progress the goals of technology education; rather, it is being driven by a desire to improve Science and Mathematics education in order to increase the flow of STEM people into the workforce and to improve STEM literacy in the population (Barlex, 2008). Despite the idea that Mathematics and Science education can be improved by combining them with Engineering and Technology this has not been proved, and the concept of STEM literacy is a bit befuddling and ill defined.

Much has been written about the synergistic relationships among Science, Mathematics, and Technology, particularly between Science and Technology. A succinct summary of these relationships has been provided by Kimbell and Perry (1991):

> Science provides explanations of how the world works, mathematics gives us numbers and procedures through which to explore it, and languages enable us to communicate within it. But uniquely, design & technology empowers us to change the made world. (p. 3)

Allied with the STEM approach is a Technology education revisionary movement toward adding Engineering in schools, particularly in U.S. schools. Technology educators who promote this approach do so out of the frustration that has come from the absence of general recognition of Technology education after many years of advocacy, and they propose it as an adjustment to the focus of Technology education (Gattie & Wicklein, 2007). The fact that William Wulf, the President of the National Academy of Engineering wrote the foreword for the “Standards for Technological Literacy” (International Technology Education Association, 2000) is heralded as a significant benediction (Lewis, 2005) to the shift from Technology education to Engineering (Rogers, 2006). The rationales are various and dubious, but they are similar to those presented for the STEM agenda:

- Increase interest, improve competence, and demonstrate the usefulness of mathematics and science (Gattie & Wicklein, 2007).

- Improve technological literacy (Rogers, 2005), which promotes economic advancement (Douglas, Iversen, & Kalyandurg, 2004).

- Provide a career pathway to an engineering profession (Dearing & Daugherty, 2004; Wicklein, 2006).

- Improve the quality of student learning experiences (Rogers, 2006).

- Give preparation for university engineering courses (Project Lead the Way, 2005).

- Elevate technology education to a higher academic and technological level (Wicklein, 2006).

Although there has been considerable discussion on this topic, there seems to be very little discussion about the similarities, differences, and the relationship between Technology and Engineering as school subjects. STEM is a confused acronym in which Engineering has a different type of relationship to Technology than Science does to Mathematics. This is because Engineering is actually a subset of the broad area of Technology. For example, the Science equivalent would be to link Science, Biology, and Mathematics. While some apologists have developed rationales for the consideration of Technology as a discipline (Dugger, 1988), it actually is interdisciplinary, and it relates to Engineering, along with a range of other disciplines in both the sciences and the arts.

Because of the aforementioned suspicion of any alliances between Technology and other subjects, this author's intent at the beginning of this article was to search Engineering and Technology curricula and other literature, determine the differences, and make consequent conclusions. However, after researching this topic, it became evident that this would not be a simple task. Thus, the primary focus of this article is to determine if the main areas of deviation between Engineering education and Technology education exist in the nature of the process and the definition of relevant knowledge.

Process

Contrasted with an historical focus on Engineering knowledge, the nature of the Engineering process has received more attention (Malpas, 2000). The procedural terminology for Engineering education is generally the same as that used in Technology education – for example, formulating a problem, generating alternatives, and analyzing and evaluating (Eggert, 2005). Eggert (2005) elaborated that in Engineering,

> whether we are designing a component, product, system or process, we gather and process significant amounts of information . . . We try to determine desirable levels of performance and establish evaluation criteria with which we can compare the merits of alternative designs. We consider the technical, economic, safety, social or regulatory constraints that may restrict our choices. We use our creative abilities to synthesize alternative designs . . . (p. 2).

Both the language and the sentiment of this description of Engineering design would be familiar to Technology education teachers. Although there are many descriptions of the Engineering process, just as there are many explanations of the Technology process, the general and superficial judgment is that there are no significant differences.

With the promotion of Engineering as a focus for Technology education, an analysis of the nature of the Engineering process should be added. The depth of this analysis varies from "engineering design is the same as technological design" (International Technology Education Association, 2000, p. 99) to the idea that the Engineering design process centers around the four representations of semantic, graphical, analytical, and physical (Ullman, 2003). In his summary of design in Engineering, Lewis (2005) pointed out this remains an area of contention, with "some in the engineering community believing that design lacks the definitive content and rigor [that typifies engineering], while others contend that creativity cannot be taught" (p. 45), and other tensions within Engineering center on the questionable value of hands-on learning that accompanies design.

Lewis (2005) quoted Peterson's (1990) qualification that design is not a science and has no rigorous rules for progression. This presents problems for more traditional Engineering educators who see the Engineering process as predictable and quasi-scientific. In contrast, Cross (2000) perceived that the design process, while variable and evolving, tends to become formalized. To further indicate the diversity of approaches to Engineering design, the Cambridge Engineering Design Centre is developing evolutionary computer-based methods to optimize conflicting design criteria in a diverse range of areas, such as improving hybrid electric vehicle drive systems, trading-off reduction in pollutants and noise in aero-engines, and designing cheaper and more compact space satellites (Cambridge Engineering Design Centre, 2009).

Gattie and Wicklein (2007) concluded that the fundamental difference between the design processes in Engineering and Technology is the absence of mathematical rigor and analysis in technology that precludes the development of predictive results and consequent repeatability. This reflects Lewis's (2005) earlier discussion that if Technology educators are to embrace Engineering, one implication is that more Science and Mathematics would need to be taught to students, so that they could approach the devising of design solutions from a more analytic framework, thus enabling them to have predictability about the design outcome prior to its production.

This thinking has led a number of authors to divide design into conceptual design and analytic design, the former being common in Technology education and the latter a part of Engineering. Analytic design may be utilized to ensure functionality and endurance, and it involves static and dynamic loads and consequent stresses and deflections. Thermodynamic analyses may be required in order to make yield and fatigue judgments.

Conceptual design is less predictive. Success in Technology education is determined by what "works," which is initially defined by a range of criteria, and through a process of research and idea development, a solution is first produced and then judgments are made about its success. In Technology education, it is not possible to predict what will work with certainty because of the diverse qualitative variables involved. It is a process of experimentation and modelling that leads to a solution. In Engineering, experimentation and modelling lead to the verification of a solution, prior to its development. This is obviously essential, given the nature of engineering projects.

This difference may be illustrated by a model bridge-making exercise, which is a common project in both Engineering and Technology education. In Technology education, after students develop an understanding of design factors, they will then construct a model bridge and test it to destruction. They will analyze the model and the testing process to further develop their understanding. They possibly will construct another model as a result of the information they have discovered. In Engineering, students will develop an understanding of the design factors, and then analyze all the variables to ensure that the model will conform to the design requirements. Next, they will construct the model. If the testing of the bridge indicates that it does not meet specifications, the design has failed.

Thus for engineers, the design criteria are more deterministic, implying that a more limited range of outcomes are possible and there is less opportunity for divergent and creative ideas to develop. For technologists, the design criteria are more open, permitting a broader range of acceptable outcomes.

Herein lies a key difference between Engineering design and Technology education. "The most notable difference in the design process is that engineering design uses analysis and optimization for the mathematical prediction of design solutions" (Kelley, 2008, p. 51). The use of Science and Mathematics to develop a body of knowledge that enables the analysis and testing of prototype solutions prior to their production is a feature of Engineering. This does not mean that Engineering design is necessarily more informed (McCade, 2006), it is just a different type of design that requires more prerequisite knowledge and is less divergent in outcome possibilities.

Petroski (1996) characterized this difference as the importance of failure considerations, such as "the ability to formulate and carry out the detailed calculations of forces and deflections, concentrations and flows, voltages and currents, that are required to test a proposed design on paper with regard to failure criteria" (p. 89). This prediction of failure, while still present in Technology education activities, is less pervasive and not as crucial.

A discussion of this difference should take place in a context of general or pre-vocational education. Engineering as a school subject that has a pre-engineering or a vocational goal, which is the framework for most of the cited discussion, will necessarily employ a design process that is aligned with the nature of Engineering design: one that is more analytic and based on a defined body of knowledge. However, some authors and curriculum development projects promote Engineering design in lower secondary and even primary schools, which at this level should not be vocational but general. A design process at lower levels of education that prioritizes analytic design and is preceded by the mastery of a body of knowledge and consequently limits creativity and divergent thinking is inappropriate. Projects such as "Primary Engineer" are in fact engaging in Design and Technology and presumably use the Engineering label for reasons related to status or recognition.

Technology Education in Western Australia

Prior to the application of this discussion to a specific context, an introduction to the Technology education curriculum in Western Australia follows. In this area, in 2000, a state curriculum framework was introduced that included eight learning areas, one of which was Technology. These learning areas were developed and used in schools as a trial for implementation in 2005. The "Technology Learning Area Framework" was a radical departure from previous curricula in the area, which were content specific in a quite detailed way and focused on teacher inputs. The new framework was outcomes based and specified content in a general way. It brought together a number of previously discrete subjects that included a similar process focus and philosophical basis. The subjects were Home Economics, Design and Technology, Computing, Agriculture, and Business Studies.

The kindergarten to year 10 Technology curriculum is defined in terms of outcomes and content. The seven outcomes are:

1. TECHNOLOGY PROCESS. Students apply a technology process to create or modify products, processes, systems, services, or environments to meet human needs and realize opportunities.

2. MATERIALS. Students select and use materials that are appropriate to achieving solutions to technology challenges.

3. INFORMATION. Students design, adapt, use, and present information that is appropriate to achieving solutions to technology challenges.

4. SYSTEMS. Students design, adapt, and use systems that are appropriate to achieving solutions to technology challenges

5. ENTERPRISE. Students pursue and realize opportunities through the development of innovative strategies designed to meet human needs.

6. TECHNOLOGY SKILLS. Students apply organizational, operational, and manipulative skills appropriate to using, developing, and adapting technologies.

7. TECHNOLOGY IN SOCIETY. Students understand how cultural beliefs, values, abilities, and ethical positions are interconnected in the development and use of technology and enterprise.

Table 1 gives an idea of the relationship between outcomes and content. The content has been developed into a scope and sequence, but it is quite broad and open to interpretation.

During the 2000-2005 period of progressive implementation of the Framework, it became clear that it did not encompass the last two years of secondary school. In these years, students at school did one of the following: prepared for university entrance, began preparatory vocational studies for later transfer to a tertiary vocational institution, or studied school designed and assessed subjects. In 2001, the government reviewed the upper secondary curriculum (Curriculum Council, 2001). Among the recommendations of the review were to replace the existing 270 subjects available to students with 50 courses of study, each of which would have the same preparatory status for either university entrance or vocational studies. The courses were to be outcomes based and consistent with the previously devised and implemented Learning Area Framework.

This was a particularly positive outcome for the Technology Learning Area Framework, which up until this time did not offer students courses that could be used for university entrance; the focus was on vocational preparation for other post-school destinations. Of the 50 proposed courses, those that represent a continuation of Technology studies in the lower secondary years are listed in Table 2.

The significance of the change for Technology education is obvious in the number of technology-related study options that are now available to students, compared with the former situation in which they had none. Students can

Table 1. Design and Technology Outcomes and Content.

Technology Process
- Investigating
    - Processes
    - Features, properties and use
- Devising
    - Generating and communicating designs
    - Conventions and considerations
- Producing
    - Techniques
    - Considerations
- Evaluating
    - Outputs
    - Methods

Materials
- The nature of materials
    - Form and attributes
    - Context and impact
- The selection and use of materials
    - Investigating
    - Devising
    - Producing
    - Evaluating

Information
- The nature of information
    - Form and attributes
    - Context and impact
- The creation of information
    - Investigating
    - Devising
    - Producing
    - Evaluating

Systems
- The nature of systems
    - Form and attributes
    - Context and impact
- The use and development of systems
    - Investigating
    - Devising
    - Producing
    - Evaluating

Enterprise
- Enterprising attitudes
    - Maximising opportunities
- Enterprising capabilities and skills
    - Generating ideas
    - Communicating and managing
    - Evaluating outputs
    - Evaluating methods

Technology Skills
- Organizational skills
    - Materials
    - Information
    - Systems
- Operational skills and manipulative skills
    - Materials
    - Information
    - Systems

Technology in Society
- Influencing factors
- Consequences
    - Process – investigating
    - Materials
    - Information
    - Systems

Note. Adapted from “Engineering Studies” by Curriculum Council, 2008, Perth: Curriculum Council.

Table 2. Technology-Related Courses Years 11-12.

Accounting and Finance
Agriculture (Animal or Plant)
Applied Information Technology
Automotive Engineering and Technology
Aviation
Business Management and Enterprise
Career and Enterprise Pathways
Construction
Design
Engineering Studies
Food Science and Technology
Materials, Design, and Technology
Media Production and Analysis

select from these subjects and use their achievement as the basis for further university or vocational studies. These new courses have been and are being progressively implemented in schools from 2006 through 2011.

Technology is taught as general education to grade 10, and then a range of more specific subjects are available for students in grades 11-12. In this curriculum, the technology process is elaborated according to these two stages: lower secondary and upper secondary. The curriculum is different at these two stages: lower secondary is a part of the K-10 general education curriculum, and upper secondary includes the type of subjects listed in Table 2 (pre-vocational education). Some elements of the technology process are listed in Table 3, and they indicate the difference between these stages.

In support of the previous literature review, it is clear that the process takes on a different focus when students progress beyond general Technology education into a more specific technological area such as Engineering. The curriculum becomes more analytical, more explicitly related to Mathematics and Science, and more focussed on industry and commercial standards.

Table 3. Aspects of the Technology Process.

TECHNOLOGY PROCESS	
Lower Secondary (Yr 8-10)	**Upper Secondary (Yr 11-12)**
Key design features and properties of technologies can determine functionality and suitability to use	Mathematical and scientific analytical methods applicable when examining the functionality and suitability for use of particular technologies
Strategies for generating designs and plans that meet specified standards and criteria (e.g., how to find appropriate standards and criteria)	Ways to plan and design solutions to technology challenges that incorporate analysis of detailed factors of production (e.g., choices of materials, techniques and costs, people needed)
Functional, aesthetic, social, and environmental issues to be addressed when devising solutions to technology challenges	Mathematical and scientific principles appropriate for use in developing plans and proposals
How to meet detailed specifications and standards when developing products, systems, services, and environments	How to meet detailed specifications and market/ commercial standards when developing products, systems, services, and environments
Methods of organizing and maintaining a variety of tools, resources, and equipment	Industry-standard risk management strategies
Predetermined, detailed specifications and standards that can be used to evaluate personal work	Commercial specifications and standards of quality, presentation, and performance for evaluating technology products

The different approaches to design taken by Engineering and Technology indicate that Technology education is more appropriate as a component of general education.

Knowledge

The initial hypothesis of this discussion was that the scope of Technology is broader than that of Engineering. If it were accepted that Engineering is a subset of Technology, and there are many Technology areas that are not Engineering (architecture, industrial design, biotechnology, computing), this would seem to be a plausible hypothesis. Therefore, if Technology education deals with the breadth of Technology, then Engineering as a subject would be more limited. Given that one of the virtues of Technology is that teachers can choose to teach aspects that are of interest to them and relevant to their students, it would seem that limiting this scope would be a disadvantage.

However, the scope of Engineering in some contexts is presented as very broad. In his book on Engineering Design, Eggert (2005, p. 16) refers to the following roles of engineers in the product realization process: sales engineer, applications engineer, field service engineer, industrial engineer, design engineer, materials engineer, industrial engineer, manufacturing engineer, quality control engineer and project engineer. In an educational context, the New South Wales Engineering Studies Syllabus (Board of Studies, 2009) lists the following areas of Engineering as those from which study modules will be developed: aerospace, aeronautical, agricultural, automotive, bioengineering, chemical, civil/structural, electrical/electronic, environmental, marine, manufacturing, materials, mechanical, “mechatronic,” mining, nuclear, and telecommunications. This author’s hypothesis that the definition of the knowledge that accompanies Engineering and Technology will be different, with the former both more limited and more defined than the latter, would not seem to be as plausible as originally thought. Although this list of Engineering fields is broad, a defined body of knowledge exists for each area, which becomes a discrete curriculum unit.

Engineering knowledge is proposed by some to be taught prior to the application of that knowledge, because it can be defined, and then it can inform the design process. “The idea is that design is informed, as opposed to being the result of a guess or multiple guesses” (McCade, 2006, p. 73). For example, the New York State Center for Advanced Technology Education proposed the development of prerequisite skills and knowledge before the design process is utilized (McCade, 2006). Petroski (1998), however, noted that design should be taught to students early in their Engineering education, which would enable them to achieve significant procedural understanding.

A similar debate exists among technology educators. Some propose that students should master a range of manipulative skills and materials understandings before they proceed to engaging in design, so that their design work can be informed, reasonable, and possible (e.g., Merrill, Custer, Daugherty, Westrick, & Zeng, 2008). The alternative proposition is that in this approach design thinking would be constrained by the skill and material understandings that students possess, which would consequently limit creativity and innovation, so the skills involved in learning how to design should be taught and practiced at the same time as manipulative skills and the study of materials (Johnsey, 1995; Pavlova & Pitt, 2000). A pedagogical argument is invoked in support of this latter approach, which states that skills and knowledge are more effectively learned if they are taught at the time of need. In this case, need generated through problem solving because this allows students to immediately apply the skills and knowledge they have obtained in response to their felt need.

This latter approach, of concurrent experiences in the development of procedural and content knowledge, highlights the question of what knowledge is relevant in the study of both Engineering and Technology. If a particular content area of Engineering is being taught, such as civil or automotive, then there is a defined and acceptable body of knowledge related to that area which forms the parameters for the development of design projects. However, this is not the case with Technology where there is no defined body of knowledge, so the question arises: What knowledge is relevant?

The answer to this question highlights the difference between Engineering and Technology. In Technology education, the relevance of technological knowledge to a problem or design brief is defined by the nature of the problem. The information that is needed to progress the solution of a technological problem becomes the body of relevant knowledge, which of course cannot be defined prior to analyzing the problem. This also specifies the accompanying pedagogy in that content cannot be taught in the absence of a design problem. The design problem is analyzed, possible pathways to a solution are projected, and the pursuit of the solution determines the knowledge that is relevant.

In Engineering studies, the context, which defines the relevant body of knowledge, is predetermined, be it chemical, marine, automotive, and so forth. Because the content determines relevant knowledge and is not dependent on the nature of the design problem, the task for the student is different in Engineering than Technology.

In the light of this discussion it is useful to examine some of the Engineering curriculum. As explained previously, in a number of Australian states, students study Design and Technology to the tenth grade; they then have the option of progressing to study Engineering in grades 11 and 12. A brief description of the nature of these Engineering studies is as follows:

During the course Engineering studies in Western Australia, “students will explore how the design of structures, machines, products and systems have become increasingly sophisticated over time to improve our quality of life. They will develop an insight into how engineering has influenced all aspects of our lives by impacting on cultures, societies and environments. The course provides challenging, practical ways and opportunities for students with different interests to design and make things by applying engineering principles to solve problems and meet particular needs or market opportunities” (Curriculum Council, 2001, p. 1).

The course was originally conceived as design focussed, broadly covering a range of Engineering-related areas of study in a practical way. However, during its development, some more conservative university Engineering educators became involved, and the course has evolved into a quite limited approach to Engineering. Despite the statement that the “course content is sufficiently diverse to provide students with the necessary foundation to meet employment needs in a range of occupations not limited to the engineering industry” (Curriculum Council, 2008, p. 3), there is a core plus three specialist fields that provide options for study:

CORE:	Engineering design and process enterprise, environment and community
SPECIALIZATION:	Mechanical engineering, or electronic/electrical engineering, or systems and control.

Therefore, even though this includes some general aspects, the focus is quite vocational.

In New South Wales, the subject Engineering Studies “develops knowledge and understanding of the profession of engineering”

(Board of Studies, 2009, p. 6), but this includes quite a broad focus, with the following rationale:

> No longer do engineers only formulate problems, provide solutions and integrate technical understanding. Key responsibilities for the profession now include responsible wealth creation, taking full responsibility of ethical considerations and the aim of sustainability in meeting the needs of society. With such key responsibilities, engineers now place increased importance on areas such as communication, synthesis and analysis of information, management skills and teamwork. (p. 6)

The breadth of approach in this course is further illustrated by the modules from which it is constructed – these are in the areas of household appliances, landscape products, braking systems, bio-engineering, civil structures, personal and public transport, lifting devices, aeronautical engineering, and telecommunications engineering. The study of all these modules is compulsory for each student.

In the state of Queensland, the title of the subject that is available to secondary students, Engineering Technology (Queensland Studies Authority, 2004), muddies the waters of this discussion further. It does not mention preparation for the engineering profession, it does however say that this subject should benefit all students by developing their technological literacy through the provision of real-life problem-solving activities in a wide range of student interest areas. Students must study four (or more) of the following areas: energy technology, environmental technology, manufacturing technology, communication technology, construction technology, and transportation technology.

In general, it seems that even though the rationale for studying Engineering in the final years of secondary schooling has a pre-vocational focus, it also has a more general focus that may apply to students who are interested in broad technical areas rather than specific preparation for studying Engineering at a university. Universities that specify high school Engineering as a prerequisite for entering Engineering courses tend to emphasize the vocational aspect of the school subject.

Conclusion

The process and the knowledge related to Technology education and Engineering studies are different; Technology education is more appropriately a component of general education, and Engineering studies are more vocational. The implication in terms of the school curriculum is that Technology education is a component of primary and lower secondary education, and Engineering is part of the upper secondary schooling. This position is summarized in Table 4:

Table 4. Lower and Upper Secondary Technology Studies.

Schooling	Up to year 10	Years 11-12
Subject	Design and Technology	Engineering
Focus	General	Vocational
Process	Designerly	Analytic, Math/Sc dependent
Knowledge	Defined by the problem	Defined by the context

The process of Engineering design involves problem factor analysis, which is dependent on an understanding of applicable Science and Mathematics. This is not a significant aspect of the type of design carried out in Technology education. It provides less scope for the achievement of the general goals related to creativity and lateral thinking because it is more constrained.

The knowledge needed to solve a Technology education problem is ill defined until the nature of the problem is fully explored and the design process is underway. The knowledge needed to solve an Engineering problem is predefined by the type of engineering that is being studied, so there is less scope for the student to explore and consequently define relevant knowledge.

Technology education is a more appropriate curricula vehicle for the achievement of general technological skills than is Engineering, but a system of education where Engineering studies at upper secondary school follows a general based Technology education at the lower secondary level would be a logical progression, and a "good" move for Technology education.

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