

Engineering: good for Technology Education?

P John Williams

Edith Cowan University, Australia and University of Waikato, New Zealand

Abstract

Recent curriculum changes in the educational system of Australia have resulted in study options being available in Engineering for senior secondary students to use for university entrance. 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 paper.

Introduction

I have always been suspicious of the agendas that accompany a proposed link between technology and other curriculum areas. When Science and Technology as a subject is 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 rarely translate 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 served the need for reform in Science and Mathematics (LaPorte and Sanders, 1993) rather than the goals of Technology. More latterly Engineering has been brought into the mix with a number of Science, Technology, Engineering and Maths (STEM) projects being developed, most significantly, in terms of numbers and influence, in the UK and USA. Again, the agenda for this type of amalgamation is not being driven by a desire to progress the goals of technology education, but 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 with Engineering and Technology is not proven, and the concept of STEM literacy is a bit befuddling and ill defined, nevertheless these are the stated goals of STEM Projects.

Much has been written about the synergistic relationships between Science and Mathematics, and Technology, particularly Science and Technology. A succinct summary of the relationships is 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.

Allied with the STEM approach, is a Technology Education revisionary movement toward Engineering in schools, particularly in the US. 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 propose it as an adjustment to the focus of Technology Education (Gattie and 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 similar to those presented for the STEM agenda:

- Increase interest, improve competence and demonstrate the usefulness of mathematics and science (Gattie and Wicklein, 2007)
- Improve technological literacy (Rogers, 2005) which promotes economic advancement (Douglas, Iversen, & Kalyandurg, 2004, p. 3).
- Provide a career pathway to an engineering profession (Dearing and Daugherty, 2004; Wicklein, 2006)
- Improve the quality of student learning experiences (Rogers, 2006)
- Preparation for university engineering courses (Project Lead the Way, 2005)
- Elevate technology education to a higher academic and technological level (Wicklein, 2006)

But there seems to be little clear discussion about the similarities, differences and their relationship between Technology and Engineering as school subjects. STEM is a confused acronym: Engineering has a different type of relationship to Technology than does Science or Mathematics, because it is actually a sub-set of the broad area of technology. The Science equivalent would be to link Science, Biology and Mathematics, for example. While some apologists have developed rationales for the consideration of technology as a discipline (Dugger, 1988), it really is interdisciplinary, and relates to engineering, along with a range of other disciplines in both the sciences and the arts.

Because of my fore stated suspicion of any alliances between Technology and other subjects, my intent at the beginning of this paper was to search Engineering and Technology curricula and other documentation and determine the differences and make consequent conclusions. However, inevitably the process was not as simple. My initial feeling, and the main focus of this paper, was that the main areas of deviation between Engineering Education and Design and Technology resided 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 recently (Malpas, 2000). The procedural terminology used is generally the same as used in Design and Technology – for example formulating a problem, generating alternatives, analysing and evaluating (Eggert, 2005). 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...' (Eggert, 2005, p 2)

Both the language and the sentiment of this description of engineering design would be familiar to Design and Technology teachers. While there are many descriptions of the engineering process, just as there are of the technology process, the general and superficial judgement is that there are no significant differences.

Together with the promotion of Engineering as a focus for Technology Education, is an analysis of the nature of the engineering process. The depth of this analysis varies from 'engineering design is the same as technological design' (International Technology Education Association, 2000) to 'the engineering design process centres around the four representations of semantic, graphical, analytical and physical' (Ulman, 2003).

In his summary of design in engineering, Lewis (2005) points out this remains an area of contention, with 'some in the engineering community believing that design lacks the definitive content and rigour [that typifies engineering], while others contend that creativity cannot be taught' (p45), and other tensions within Engineering centre on the questionable value of hands on learning that accompanies design.

Lewis 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. On the other hand Cross (2000) perceived that the design process, while variable and evolving, is tending 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, more compact space satellites (Cambridge Engineering Design Centre, 2009).

Gattie and Wicklein (2007) conclude that the fundamental difference between the design processes in engineering and technology is the absence of mathematical rigour and analysis in technology that precludes the development of predictive results and consequent repeatability. This reflects Lewis' (2005) earlier discussion that if technology education is 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 frame and so enable 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 Design and Technology education and the latter a part of Engineering. Analytic design may be utilized to ensure functionality and endurance and involves static and dynamic loads, and consequent stresses and deflections. Thermodynamic analyses may be required in order to make yield and fatigue judgements.

Conceptual design is less predictive. Success in Design and Technology 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 produced and then judgements are made about its success. In Design and Technology, it is not possible to predict what will work with certainty because of the manifold 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, commonly done in both Engineering and Design and Technology Education. In Design and Technology, after

developing an understanding of the design factors, students will construct a model bridge and then test it to destruction. Then they will analyse the model and the testing process to further develop their understanding, and then possibly construct another model as a result of the new information they have discovered. In Engineering, students will develop an understanding of the design factors, and then analyse all the variables to ensure that the model will conform to the design brief requirements, and then construct the model. If the testing of the bridge indicates that it does not meet specifications, then the design has failed.

So in Engineering, 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. In Design and Technology, the design criteria are more open permitting a broader range of acceptable outcomes.

Herein lays a key difference between Engineering design and Design and Technology. ‘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). 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) characterizes this difference as the importance of failure considerations: ‘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 Design and Technology activities, is less pervasive and not as crucial.

A discussion of this difference needs to take place in a context of general or pre/vocational education. Engineering as a school subject that has a pre-engineering or vocational goal, which is the context for most of the cited education 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 these lower levels of education which 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’ (2009) are really 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 2000 a state curriculum framework was introduced in Western Australia, covering eight learning areas, one of which was Technology. The Learning Areas were to be developed and trialled in schools for implementation in 2005. The Technology Learning Area Framework was a radical departure from previous curriculum 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 which had a similar process focus and philosophical basis. The subjects were Home Economics, Design and Technology, Computing, Agriculture and Business Studies.

The K-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 realise 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 realise opportunities through the development of innovative strategies designed to meet human needs.
6. **TECHNOLOGY SKILLS.** Students apply organisational, 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.

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

<p>Technology Process</p> <ul style="list-style-type: none"> • Investigating <ul style="list-style-type: none"> • Processes • Features, properties and use • Devising <ul style="list-style-type: none"> • Generating and communicating designs • Conventions and considerations • Producing <ul style="list-style-type: none"> • Techniques • Considerations • Evaluating <ul style="list-style-type: none"> • Outputs • Methods <p>Materials</p> <ul style="list-style-type: none"> • The nature of materials <ul style="list-style-type: none"> • Form and attributes • Context and impact • The selection and use of materials 	<p>Systems</p> <ul style="list-style-type: none"> • The nature of systems <ul style="list-style-type: none"> • Form and attributes • Context and impact • The use and development of systems <ul style="list-style-type: none"> • Investigating • Devising • Producing • Evaluating <p>Enterprise</p> <ul style="list-style-type: none"> • Enterprising attitudes <ul style="list-style-type: none"> • Maximising opportunities • Enterprising capabilities and skills <ul style="list-style-type: none"> • Generating ideas • Communicating and managing • Evaluating outputs • Evaluating methods
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<ul style="list-style-type: none"> • Investigating • Devising • Producing • Evaluating <p>Information</p> <ul style="list-style-type: none"> • The nature of information <ul style="list-style-type: none"> • Form and attributes • Context and impact • The creation of information <ul style="list-style-type: none"> • Investigating • Devising • Producing • Evaluating 	<p>Technology Skills</p> <ul style="list-style-type: none"> • Organisational skills <ul style="list-style-type: none"> • Materials • Information • Systems • Operational skills and manipulative skills <ul style="list-style-type: none"> • Materials • Information • Systems <p>Technology in Society</p> <ul style="list-style-type: none"> • Influencing factors • Consequences <ul style="list-style-type: none"> • Process – investigating • Materials • Information • Systems
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Table 1. Design and Technology Outcomes and Content.

During the 2000-2005 period of progressive implementation of the framework, it became clear that the Framework did not encompass the last two years of secondary school. In these years students at school prepared for university entrance, began preparatory vocational studies for later transfer to a tertiary vocational institution, or did school designed and assessed subjects. In 2003 the government implemented a review of the upper secondary curriculum (Curriculum Council, 2003). 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, which up until this time could not offer students any post compulsory courses that they could use for university entrance; the focus was on vocational preparation for other post school destinations. Of the 50 courses proposed, those that represent a continuation of Technology studies in the lower secondary years are listed in Table 1.

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

Table 1. Technology related Year 11-12 Courses

The significance of the change for Technology Education is obvious in the number of technology related study options students now have in their senior schooling, compared with the former situation in which they had none. Students can select from these subjects and use their achievement as the basis for further university or vocational studies. These new Courses are being progressively implemented in schools between 2006-2011.

So Technology is taught as general education to Year 10, and then a range of more specific subjects are available for students in years 11-12, the last 2 years of their secondary education. In this curriculum, the technology process is elaborated according to stages, and the two relevant stages here are early adolescence and late adolescence – lower secondary and upper secondary. The curriculum is different at these two stages, lower secondary being a part of the K-10 general education curriculum, and upper secondary being the type of subjects listed in Table 1, more pre-vocational education. Some elements of the technology process are listed in Table 2 and indicate the difference between these stages.

TECHNOLOGY PROCESS	
Early Adolescence (Yr 8-10)	Late Adolescence (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 organising 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
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Table 2. Aspects of the Technology Process.

In support of the previous literature discussion, it is clear that the process takes on a different focus when students progress beyond general Design and Technology into a more specific technological area such as Engineering; it becomes more analytical, more explicitly related to Mathematics and Science, and more focussed on industry and commercial standards. The different approaches to design taken by Engineering and Design and Technology indicate that Design and Technology is more appropriate as a component of general education.

Knowledge

My initial hypothesis was that the scope of technology is broader than that of engineering. If it is 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. So if Design and Technology potentially dealt with the breadth of technology, then Engineering as a subject would be essentially 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 being very broad. In his book on Engineering Design, Eggert (2005, p16) 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, bio, chemical, civil/structural, electrical/electronic, environmental, marine, manufacturing, materials, mechanical, mechatronic, mining, nuclear and telecommunications. My hypothesis that the definition of the knowledge that accompanies Engineering and Design 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 I thought. Although, while this list of areas of engineering 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). For example, the New York State Centre for Advanced Technology Education proposes the development of prerequisite skills and knowledge before the design process is utilized (McCade, 2006). Petroski (1998) however holds that design should be taught to students early in their engineering education which will enable them to achieve significant procedural understanding.

A similar debate exists amongst technology educators. There are those who propose that a range of manipulative skills and materials understandings should be mastered by students

before they proceed to engaging in design, so that their design work can be informed, reasonable and possible. 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 materials understandings. A pedagogical argument is invoked in support of this latter approach which states that skills and knowledge are more effectively learnt if they are taught at the time of need, in this case need generated through solving problems, because this allows for immediate application in response to students 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 Engineering and Design and Technology. If a particular context 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, there is no defined body of knowledge, so the question arises, what knowledge is relevant?

The answer to this question defines a difference between Engineering and Design and Technology. In Design and Technology, 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 the analysis of the problem. This therefore also specifies the accompanying pedagogy in that content cannot be taught in the absence of a design problem. The design problem is analysed, possible pathways to a solution are projected, and then 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, etc. Because the context determines relevant knowledge, it is not dependent on the nature of the design problem, and so the task for the student is different in engineering and technology.

In the light of this discussion it is useful to examine some Engineering curriculum. In a number of Australian states, students study Design and Technology to year 10, and then have the option of progressing to study Engineering in Year 11-12, the last 2 years of their secondary schooling. A brief description of the nature of these Engineering studies follows.

In the course Engineering Studies in Western Australia, “students will explore how the designs 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, 2004, 1).

The course was originally conceived as being design focussed, broadly covering a range of engineering related areas of study in a practical way. However, during its development, some more conservative university engineer 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, p3), there is a core and three specialist fields which provide options for study:

CORE: Engineering design and process
Enterprise, environment and community

SPECIALIZATION: Mechanical engineering, or
Electronic/electrical engineering, or
Systems and control.

So while there are 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, p6) but with quite a broad focus, the rationale being that:

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 (p6).

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 which is available to final year secondary students, Engineering Technology (Queensland Studies Authority, 2004), muddies the waters of this discussion further. It does not mention preparation for the engineering profession, but 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 have to study at least four of the following areas: energy technology, environmental technology, manufacturing technology, communication technology, construction technology and transportation technology.

So in general, it seems that while 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 more interested in broad technical areas rather than specific preparation for studying Engineering at university. Universities that specify school Engineering as a pre-requisite for entering Engineering courses tend to emphasize the vocational aspect of the school subject.

Conclusions

The conclusion of this discussion is that the process and the knowledge related to Design and Technology and Engineering Studies are different and that Design and Technology is more

appropriately a component of general education, and Engineering studies are more vocational. The implication in terms of the school curriculum is that Design and Technology is a component of primary and lower secondary, and Engineering is part of the upper secondary schooling. This position is outlined in the table below.

Schooling	K-10	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 Design and Technology. 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 Design and Technology 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 pre-defined by the type of engineering that is being studied, so there is less scope for the student to explore and consequently define relevant knowledge.

Design and Technology 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 follows a general based of Design and Technology would be a logical progression, and 'good' for Technology Education.

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