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Learning to Design: the Continuum of Engineering Education*

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The purpose of this paper is to explore the extent to which curriculum initiatives in school-based design and technology education and undergraduate engineering education are converging in their intent to provide students with 'designerly' ways of knowing. The literature that describes the nature of design and designing, the nature and purposes of design and technology education in elementary and secondary schools, and the place of design in engineering education serves to frame the second part of the paper. This will describe two curriculum initiatives, one elementary and one secondary, which introduce a powerful pedagogy for teaching, learning and assessment in technology education centred on both designing and making products. The resonance of this pedagogy with contemporary trends in engineering education are explored and discussed in the third and final section of the paper. Overall, the paper speculates on the question: Is design education for engineering a continuum?

Keywords: Design education, elementary education, secondary education, curriculum development, pedagogy, progression

INTRODUCTION

TO READERS of this journal, the observation that most people spend most of their time in a made world will be a truism. Equally, the observation that designers conceive products that serve human needs and wants will be familiar. That everyone has the capacity, to a greater or lesser degree, to design; that consumers and the environment would benefit if design education was available for all students; and that designing can be taught to all students at any age level may be less obvious. Yet an increasing number of designers and design educators are advocating that design education is an essential part of the curriculum for all pupils, not just those entering traditional 'designerly' professions [1, 2]. According to the Department for Education and Employment in England, design education at elementary and secondary school levels can 'prepare pupils to . . . think and intervene creatively [in the made world] to improve quality of life' [3]. This would appear to be a legitimate objective for engineering education also.

The purpose of this paper is to explore the extent to which school-based design and technology education and engineering education are converging in their intention to provide students with design knowledge and skills. The paper speculates on the extent to which school-based design education provides a foundation for undergraduate engineering programmes.

REVIEW OF LITERATURE

Designing is a powerful activity that utilizes available technology to conceive and produce what we both need and want as individuals, communities and a complex global society. Designing requires creativity, intuition, intellectual rigour and choice to arrive at a solution to a problem [5]. Good design is sometimes invisible. We take it for granted because its results can be used effectively without apparent effort. Bad design is always obvious. It jars and makes life less pleasant, more difficult and sometimes downright dangerous.

A series of papers published in the journal *Design Studies* in the late 1970s and early 1980s aimed 'to establish the theoretical bases for treating design as a coherent discipline of study' [2, p. 221]. In the first of these papers, Archer defined design as 'the collected experience of the material culture . . . . Material culture comprises the ideas which govern the nature of every sort of artefact produced, used and valued by man [*sic*]. . . . The artefacts themselves are the experience, sensibility and skill that goes into their production and use' [6, p. 19]. Cross [2] in a subsequent paper, drew the following conclusions about the nature of design. First, the central concern of design is the conception and realization of new things. Second, design involves planning, inventing, making and doing. Third, at the core of designing is the language of modelling, and it is possible to develop students' aptitudes in this 'language' just as it is possible to develop aptitudes in the language of the sciences (numeracy) and in the humanities (literacy). Finally, design has its own distinct things to

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know, ways of knowing them, and ways of finding out about them.

Buchanan argues that 'the problem for designers is to conceive and plan what does not yet exist' [7, p. 17]. Ropohl notes that 'the designer has to determine spatial and temporal details which cannot yet be observed' [8, p. 69]. This activity is complex. Cross, Naughton and Walker note that 'a designer attends simultaneously to many levels of detail as he [*sic*] designs. The level of attention encompasses the range of design considerations from overall concept to small particulars. . . . Many of the small particulars only surface to be dealt with consciously when they become critical' [9, p. 29].

The tasks that designers tackle are, according to Rittel [see 10] 'wicked' in the sense that they are not merely ill-defined and multi-dimensional, but they:

- Are individual (each is unique).
- Have no definite formation (formulating the task is the designer's first step).
- Have no stopping rules (development can just go on and on).
- Have no true or false solutions (only better or worse).
- Have no complete list of operation (designers can do very different things).
- Are capable of multiple solutions (all of which may be successful in different ways).
- Have no definitive 'truth' test (design 'truth' is a value judgement and disputable.

Design and technology education in schools

The purposes of design and technology education in elementary and secondary schools vary from country to country (and from province to province in Canada and state to state in the USA). For example, the Ontario Grade 9 curriculum for technological education aims to 'enable students to become problem solvers who are self-sufficient, entrepreneurial, and technologically literate. . . . They must become critical and innovative thinkers, able to question, understand, and respond to the implications of technological innovation, as well as to find solutions and develop products' [11, p. 2].

In the USA, the *Standards for Technological Literacy* aim to provide for all States 'an essential core of technological knowledge and skills we might wish all K-12 students to acquire' [12, p. v]. The *Standards* provides a very detailed guide 'for educating students in developing technological literacy. . . . [T]he ability to use, manage, assess, and understand technology' [12, p. 9].

According to the National Curriculum in England, design and technology education:

> Prepares pupils to participate in tomorrow's rapidly changing technologies. They learn to think and intervene creatively to improve quality of life. The subject calls for pupils to become autonomous and creative problem solvers, as individuals and members of a team. They must look for needs, wants and opportunities and respond to them by developing a range of ideas and making products and systems. They combine practical skills with an understanding of aesthetics, social and environmental issues, function and industrial practices. As they do so, they reflect on and evaluate present and past design and technology, its uses and effects [3, p. 15].

Kimbell and Perry have described the distinctive contribution that design and technology make to the school curriculum in the following way: 'It is a learning experience which is unbounded by fixed bodies of traditional knowledge, and transcends the academic/practical divide' [13, p. 1]. Design and technology is a task-centred activity that requires pupils to take 'a project . . . from inception to completion within the constraints of time, cost and resources' [13, p. 5]. The design tasks are 'wicked', involving students in creative exploration, modelling futures, managing complexity and uncertainty. This task-centred activity is 'rooted in a view of the autonomous learner taking responsibility for decisions and living with their consequences' [13, p. 7].

Becoming and being a designer in schools requires pupils to learn how to design and make products and services. When pupils are designing and making they are involved in a 'characteristic . . . sequence of actions' [14, p. 3]. According to Barlex, Read, Fair and Baker [15] this sequence includes:

- perceiving a situation from the viewpoint of others whose needs the design is trying to meet;
- identifying and clarifying the issues that the emerging design must address;
- clarifying and evaluating design ideas through modelling;
- making the design;
- reflecting on both the success of the product and the efficacy of the process by which it was produced.

The learning through this sequence is held to be highly significant because it is 'challenging, enriching and empowering' (16, p. 29]. Central to this learning is the act of designing. This has been shown to be a highly demanding activity at which novice designers (school pupils) exhibit, not unexpectedly, only limited proficiency [17, 18].

A critical task for the teacher is to provide students with the opportunity to learn to make five types of design decision [19]:

- conceptual (What is the overall purpose of the design? What sort of product will it be?);
- technical (How will the design work?);
- aesthetic (What will the design look like?);
- constructional (How will the design be put together?);
- marketing (Who is the design for? Where will it be used? Where will it be sold?).

Barlex has represented these decisions visually (Fig. 1) with each type of decision at a corner of a pentagon, with each corner connected to every other corner. This inter-connectedness is an

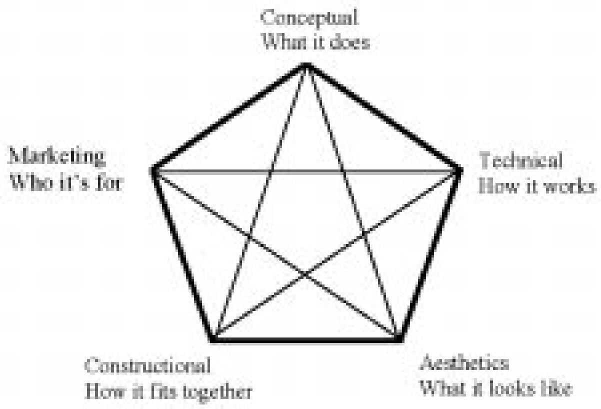

Fig. 1. The design decision pentagon.

important feature of making design decisions, for a change of decision within one area will likely affect some if not all of the design decisions that are made within the others. For example, if the way a design is to work is changed this will almost certainly affect what the design looks like and how it is constructed. It may also have far-reaching effects in changing some of the purposes that the design can meet and who might be able to use it.

Murphy and Hennessey [20] have shown that for learning in design and technology education to be meaningful, the tasks that teachers set for pupils must be authentic. According to these authors, activity is authentic if it is (a) personally meaningful and coherent, and (b) purposeful within a social framework—the ordinary practices of the culture. These two aspects of authenticity, personally meaningful and purposeful within a social framework, are interrelated but they can be thought of distinctly. In making a task that is set as a 'problem' personally meaningful, pupils must be involved in the context of the problem (e.g. an aid for a disabled child in a special school). Pupils must also be given the opportunity to make significant decisions: decisions that allow them to create solutions (e.g. pupils design an important feature of the aid, not just its colour or aesthetic elements of the shape).

To make a task purposeful, in addition to exploring the context of the problem, pupils need to see the context for its solution. This implies saying who the pupil is in the process (e.g. part of a company that produces wooden products), and the relationship to any client (e.g. the teacher of the disabled child). Thus in making bridges between school learning and everyday experience it is **not** essential that the situations in which school activities are set are 'real'. The central requirement is that they afford the pupils authentic dilemmas that 'furnish opportunities [to the pupils] to improvise new practice [i.e. to learn]' [21, p. 85].

In the context of design and technology education two types of tasks have been shown to provide (a) the necessary range of learning experiences and (b) authentic and purposeful activity [22]. The nature of these tasks, and associated issues of teaching and learning, will be addressed in a later section of this paper in the context of the Elementary Science and Technology Project, a four-year teacher professional development and curriculum materials writing initiative.

Sim and Duffy [23] provide an intriguing picture of designing as a learning activity. They argue that the designer is learning about the design that he or she is conceiving through successive iterations of a solution that give increasing clarity to the design proposal and its worth. The designer is learning about what he or she is creating as he or she creates it.

Design in undergraduate engineering education

Just as design education is now being established in elementary and secondary schools as an important part of general education, so engineering education is recognizing the centrality of design in its programmes. For example, the Accreditation Board for Engineering and Technology [24] is recognized in the United States as the sole agency responsible for accreditation of educational programmes leading to degrees in engineering. Included in the list of 11 outcomes that engineering programmes must demonstrate that their graduates have are:

- An ability to design a system, component, or process to meet desired needs.
- An ability to function on multi-disciplinary teams.
- An ability to identify, formulate and solve engineering problems.
- An ability to communicate effectively.
- The broad education necessary to understand the impact of engineering solutions in a global and societal context [24, p. 2].

The Joint Board of Moderators (JBM) in the UK, formed 'to ensure that educational programmes are in place to develop professional engineers that will continue to provide a global contribution to sustainable, economic growth and ethical standards' [25, p. 1] lists the important design attributes of an engineer, including:

a. an understanding that design is a creative process;
b. an ability to cope with the uncertainties associated with a design brief;
c. an ability to interact with team members and clients;
d. a knowledge of how to gather relevant information to inform the design process;
e. an ability to sort and synthesize information [Joint Board of Moderators, 2003].

According to the JBM, effective engineering education will, therefore:

a. introduce students to the intellectual processes of design;
b. establish a learning environment that encourages students to explore the design process for themselves;
c. learn to work as part of a team;
d. require students to present and defend their design ideas to groups of peers and mentors;
e. break down the ideology, inculcated by scientific education, that design is essentially an applied science in which application of the scientific method will allow a 'best' solution to emerge.

In Canada, the Natural Sciences and Engineering Research Council of Canada (NSERC) has established a 'Chairs in Design Engineering' programme. The objective of this programme is 'to improve the level and quality of design engineering activity within Canadian universities' [26, p. 1]. Chairs funded under the programme are expected to:

- Establish a creative and innovative undergraduate/graduate training programme that gives engineering students the opportunity to experience a functioning design environment and provides them with the [design] skills and knowledge required by the profession.
- Act as advocates for design engineering, generating an increased awareness and appreciation in both research and outside communities for all aspects of design engineering.

Hubka and Eder identified elements of 'adequate competency in designing' [27, p. 801] required of engineers. Adequate design knowledge, according to these authors, includes heuristic competency, design methods competency, systems-related competency and social competency. Sheppard & Jenison listed sixteen 'qualities expected in a design engineer and that engineering courses should be helping engineering students to develop' [28, p. 249]. These include the ability to communicate, to work effectively in a team, engage in self-evaluation and reflection, use graphical and visual representations, exercise creativity, find information and use a variety of resources, consider economic, social and environmental aspects of a problem, generate and evaluate alternative solutions, and build a prototype. Nesbit, Hummel, Piergiovanni, and Schaffer emphasized 'excellent written and oral communication skills, the ability to work both independently and as part of a team, and creativity' [29, p. 435] as essential skills for the engineer.

Harrison [4] has argued that design education for engineering is a 'consistent, progressive, academic discipline, from primary to higher education' (p. 4). Engineering understanding, capability and motivation is viewed, by Harrison, as a seamless development of design ability in which:

> Knowledge and understanding progress from the *intuitive* toward the *articulate*; skills develop from the *innate* to the *disciplined*; creativity develops from the *casual* to the *harnessed*; capability develops from the *natural* to the *disciplined combination of creativity, skill and understanding*; [and] motivation develops from *pure pleasure* from making something to *excitement and determination* to be creative and effective. [p. 4, author's italics]

Harrison views engineering education as a continuum beginning when children first interact with their environment and continuing through formal years of elementary and secondary schooling and on into undergraduate, graduate and professional training. If, as Harrison [4] has suggested, design education for engineering is a continuum, then educators at all levels must ask:

- What contribution does elementary design and technology education make to engineering education?
- In what ways does secondary design and technology education prepare students to enter into undergraduate engineering education?
- How can engineering education build on the prior learning of students?

THE CURRICULUM INITIATIVES

The principal goal in design and technology education, at both elementary and secondary levels is to engage pupils in 'doing' technology. As Kimbell & Perry have stated, the purposes is to transform the pupil 'from passive recipient into active participant. Not so much studying technology as *being* a technologist' [13, p. 7]. This goal is reflected in the approach to teaching, learning and assessment adopted by two curriculum initiatives directed by the author at the Faculty of Education, Queen's University: the *Elementary Science and Technology project* and *Young Foresight*.

The Elementary Science and Technology project: teaching children to design and make products

In September 1998, the Ontario Ministry of Education and Training introduced a new science and technology curriculum for all Grade 1–8 students [30]. Its intended purpose is wide-ranging, including providing:

> The scientific and technological knowledge and skills that will enable [students] to be productive members

> of society . . . To develop attitudes that will motivate them to use their knowledge and skills in a responsible manner . . . [To] . . . develop . . . skills that are . . . important for effective functioning in the world of work . . . [and] learn to identify and analyze problems and to explore and test solutions in a wide variety of contexts. [p. 3]

In response to difficulties reported by elementary teachers faced with implementing this new curriculum, faculty at Queen's University at Kingston designed and implemented the *Elementary Science and Technology (EST) project*, a four-year collaboration between the faculty, the Algonquin and Lakeshore Catholic District School Board, the Catholic District School Board of Eastern Ontario and 26 elementary school teachers from those two boards. The mission of EST was to:

- Develop a model of professional development that enables teachers to acquire the expertise to answer questions for themselves about teaching elementary science and elementary technology.
- Work closely with a small number of teachers who will then share their experience and understanding with other teachers in their schools and boards.
- Produce high-quality curriculum materials for science education and technology education that exemplify best practice in the two subjects [31].

The first two of these objectives were achieved though a sustained programme of professional development for teachers [32]. Activities were designed to achieve specific goals related to best professional development practices, including:

a. an increase in teacher subject knowledge;
b. an increase in teacher pedagogic knowledge (related to social constructivism and situated cognition)'
c. increases in teacher efficacy with the curriculum;
d. changes in teacher classroom practices that reflected the EST science and technology model of teaching, learning and assessment [33].

To assist teachers with the writing of curriculum materials for the design and technology component of the curriculum, the project designers developed an approach to teaching, learning and assessment that utilizes two types of tasks: Support Tasks and Design and Make Activities. This is an adaptation of a model introduced by the Nuffield Design and Technology Projects [22]. Support Tasks are short, highly structured and focused activities in which students learn appropriate knowledge, skills and understanding. A Design and Make Activity is a task in which students must design what they can make and make what they have designed.

Support Tasks are active. They require students to engage with design skills, technical understanding and making skills. While a single Support Task will usually address a quite narrow topic, a sequence of Support Tasks will lead to a student acquiring a wide repertoire of design, technical, constructional and aesthetic knowledge and skill. The effectiveness of this teaching and learning is evidenced through the quality of response to the Design and Make Activity.

A Design and Make Activity (DMA) requires students to generate and develop design ideas using two-dimensional and three-dimensional modelling. The student is then required to make a prototype product based on those ideas that can later be evaluated against its performance specification [19]. A DMA is a significant activity in which pupils have to use the knowledge, understanding and skill they have been taught in an integrated and holistic way. It forms a focal point in a teaching sequence and enables pupils to reveal what they have learned through what they can do. Design and Make Activities are authentic activities because they reflect the 'ordinary practices of a culture . . . activities that are similar to what actual practitioners do' [34, p. 4].

Designing and making a product or service presents pupils with a wide variety of learning opportunities. For example, when designing they will need to use a variety of strategies, including creative thinking, sketching and drawing, visual imagery, critical thinking, problem solving and evaluating; when making a product they will need to measure, mark, cut, shape and join materials [22]. Typically, a DMA will engage the student in:

- Describing a context.
- Identifying a need or want to be met.
- Writing a design brief (based on a context or an open design brief supplied by the teacher).
- Writing a design specification (based on a student's design brief or an open design brief supplied by the teacher).
- Conducting appropriate research.
- Evaluating the research.
- Generating ideas using 2D and 3D models.
- Developing ideas using 2D and 3D models.
- Communicating ideas using 2D and 3D models.
- Working with resistant materials to produce a high-quality prototype of the designed product.
- Evaluating the prototype.
- Evaluating the learning and identifying ways in which to improve capability.

The differences between these two types of learning tasks (DMAs and Support Tasks) can be understood as a continuum. At one end are 'open' or 'wicked' tasks (DMAs) with a wide range of acceptable outcomes. They are not merely ill-defined and multi-dimensional but also individual, have no stopping rules, and are capable of multiple solutions [10]. At the opposite end of the continuum are 'closed' tasks (Support Tasks) with a single well-defined outcome [35]. Working through closed tasks and developing their limited outcomes provides experience of, and engagement with, a particular domain and leads to the acquisition of knowledge, understanding and skills [36]. The interplay between open and closed tasks provides the means to teach pupils to design and make products [37]. Clearly there is a strong parallel between this sequence of actions and the experiences seen as necessary for learning from a constructivist viewpoint.

A broad and balanced design and technology curriculum will provide students with a series of Design and Make Activities (DMA) through which they can acquire capability, that is, the ability to purposefully pursue 'a task to some form of resolution that results in improvement (for someone) in the made world' [38, p. 50]. For example, in an EST Grade 4 unit entitled *Pop-up Pals* the design brief for the unit reads as follows: 'Design and make a pop-up book that will amuse, intrigue and inform a particular reader. The book may be for you or for someone else'. Before tackling this Design and Make Activity students complete the following Support Tasks:

- investigating pop-up books;
- exploring a box fold;
- exploring a mouth fold;
- exploring a slider;
- exploring a lift-up flap;
- exploring a rotator;
- exploring illustration styles;
- writing a design specification.

An EST unit for Grade 7 students requires them to design and make a desk lamp for a special person completing a particular task. The lamp must have a light source that is focused and fully adjustable for height and angle and an on/off switch. Before responding to this design brief students will complete the following Support Tasks:

- using a collage to generate ideas;
- exploring existing products;
- explaining what is a circuit?
- building a series circuit;
- building a parallel circuit;
- cutting and shaping acrylic;
- cutting and shaping wood.

An evaluation of the impact of EST on classroom practice in design and technology education has recently begun. Preliminary data suggest that teachers have readily adopted the DMA/Support Task model [33]. But the data also suggest that pupils require considerable practice with designing before they are able to develop the ability to make design decisions. As a result of this finding, the investigators have identified a series of questions about the characteristics and sequencing of tasks that enable pupils to learn to make design decisions and the nature of classroom interactions (teacher-pupils and pupils-pupils) that support learning to make those decisions. To this end, a three-year longitudinal study of a group of elementary pupils is being conducted that will address the following research questions:

- What are the characteristics of tasks that enable pupils to learn to make design decisions?
- What is the nature of the classroom interactions (between teacher and pupils and pupils and pupils) that support learning to make design decisions?
- What is the role of metacognition in pupils' development of 'designerly' ways of knowing?

Young Foresight: teaching students to design for the future

Young Foresight is an innovative curriculum initiative that requires students to design, but not make, products and services for the future. Students:

- develop their own design briefs;
- use advanced materials and new and emerging technologies as the basis for their design ideas;
- work in teams;
- work with mentors from industry;
- present their ideas to peers, teachers, mentors and external audiences.

Teachers and students are provided with print, video and web-based materials to support the learning. Originally developed and now widely adopted in England, Young Foresight is currently being piloted in Ontario before dissemination across Canada.

The Young Foresight approach contrasts with much current practice in technology education, which requires students to design and make products while working alone [39]. This orthodoxy constrains students' creativity and limits their achievements and experience of technology to what they can make. This, in turn, may curtail their interest in engineering. Young Foresight challenges the orthodoxy of technology education practice in seven important ways [39].

1. Young Foresight requires students to design but *not* make. If students always have to make what they design this will limit their ambition to what can be achieved with the tools, equipment, materials and time available in school. Students will learn very little about modern technologies and the way they can be used if they can only engage with technologies available in school through designing and making. Students' creativity will be severely constrained by the need to make what they have designed. However, it is important that students experience the rigour and discipline of designing what they are going to make and then making what they have designed for a significant part of their technology education experience. It is for this reason that the Young Foresight experience is limited to a maximum of 24 hours class time in Grade 9.
2. Young Foresight requires students to design products and services for the future, not for themselves or members of their family now, nor for probable immediate markets. It does this

because it wants to give young people a stake in the future; a view about what it could be like and the contribution they can make by having ideas.

3. Young Foresight requires students to develop their own design briefs. This is a much more open approach than usually taken with students of this age. As a result they have to consider the needs and wants of people in a future society and the markets that might exist or could be created.
4. Young Foresight expects students to use new and emerging technologies as the basis for their design ideas. These are technologies that will not be available in school. Young Foresight does this because it believes the best way for young people to learn about technologies that will have a large effect on all our lives is for them to think about how they could be used.
5. Young Foresight requires students to work in teams in which all members contribute to generating, developing and communicating design ideas. In the world outside school multidisciplinary teams design most complex products and services and Young Foresight wants to put students in similar situations. A person is more likely to be creative as a member of a team than as a solitary individual. This is one of the reasons why industry operates through teams rather than individuals.
6. Young Foresight does not expect the teacher to tackle this task alone. Young Foresight helps schools find mentors from industry who can work in a variety of ways to support students designing for the future.
7. Young Foresight requires students to present their ideas to their peers, their teacher and mentor and to audiences at conferences on innovation. These presentations can vary from the informal and spontaneous (commenting on a hand-written flip chart), to the formal and well rehearsed (using a data projector linked to a short documentary drama).

Young Foresight prepares students to respond positively and effectively to this unorthodox approach to design and technology education by engaging them in a two-part process. In Part 1, students complete a range of Support Tasks (provided to the teacher as a 'Toolkit', containing 17 activities) that provide them with the knowledge, skills and understanding they will need to design products for the future. In Part 2 of the Young Foresight experience, students design a product or service for the future, basing their design ideas on an advanced material or a new and emerging technology. The project has produced a series of videos to provide this information and stimulate creativity. For example, one video discusses quantum tunnelling composite (additional videos show applications of new and emerging technologies and advanced materials in the fields of materials technology, electronic communications and food technology). The material in the quantum tunnelling composite video can be summarized as follows:

> Quantum tunnelling composite is clever stuff. It comes as thin sheets or powder. It can be built into textiles or fixed to hard surfaces. In a relaxed state it is a good insulator. But when it is distorted (stretched, squashed or twisted) it becomes a conductor. The harder you stretch, squash or twist it the better it conducts.

The video then goes on to show several products that utilize these characteristics, including power tools that can take on ergonomic forms, a 'soft' keyboard that can be rolled up and washed, and a robot hand. At the end of the video, students are asked the question: What would you use it for?

When designing for the future, students must take into account four factors: technology, society, people and markets:

- The technology available to be used as the basis for design ideas will be a new and/or emerging technology shown in a video. Students will consider how the technology could be used in the new product or service but will not be concerned with manufacture.
- Students will next consider the needs and wants of the people who might use the products or services. If these do not meet the needs and wants of a sufficiently large number of people they will not be successful. Students will use their learning from Support Tasks about understanding needs and wants.
- Students will speculate about the society in which the technology will be used. This will be concerned with the prevailing values of the society, what is thought to be important and worthwhile. This will govern whether a particular application of technology will be welcomed and supported. Students will use their learning from Support Tasks on trends and sustainability.
- Students will think about the markets that might exist or could be created for the products or services. Ideally a market should be one with the potential to grow, one that will last, and one that adapts to engage with developments in technology and changes in society. Students will use their learning from Support Tasks about products and services.

Although still at the pilot stage, it is anticipated that Young Foresight will provide wide-ranging benefits to both teachers and students. Students are anticipated to become creative problem-solvers, as individuals and as members of a team, as they design for the future. They will learn to develop ideas in response to identified needs and opportunities. They will learn presentation and communication skills, and that they can have an influence on the future. Teachers will develop the expertise to handle new and challenging areas of the design and technology curriculum, widening their repertoire of teaching skills and becoming members of a highly regarded community of innovative practitioners. Data from a study in England [40] suggest, as evidenced in the quotations from teachers below, that both teachers and pupils are excited by the Young Foresight approach to teaching and learning:

- Young Foresight supports the idea of risk-taking to promote creativity, enquiry and also confidence.
- Students did much better than in normal technology lessons . . . they revealed strengths and qualities I hadn't seen before.
- Two disengaged learners produced some of their best work ever.

DISCUSSION

The desire and ability to constantly improve the made world is, according to Bronowski a unique feature of humans: 'the ability to visualize the future . . . and to represent it to ourselves as images that we project and move about inside our head' [14, p. 56]. Kimbell and Perry refer to this imaging as 'designing. . . . The process that lies at the heart of technology education' [13, p. 3]. Central to designing is generating, developing and communicating design ideas.

Design education has, until quite recently, always been related to professional education. Design education was seen in instrumental terms and associated with traditional professional and vocational preparation. But in recent years, an increasing number of educators at the elementary and secondary levels have recognized the importance of design as a part of everyone's education. There is an intrinsic educational value to teaching to all students 'designerly ways of knowing' [2]. Cross argued that design education must move away from solely instrumental aims (i.e. professional education) toward valuing design's intrinsic value as part of a general education for all students. He described how 'design has its own distinct things to know, ways of knowing them, and ways of finding out about them' [2, p. 221]. He identified five aspects of 'designerly ways of knowing':

1. designers tackle ill-defined problems;
2. their mode of thinking is solution focused;
3. their mode of thinking is constructive;
4. they use 'codes' to translate abstract requirements into concrete objects;
5. they use these codes to both 'read' and 'write' in object languages.

From these five aspects, Cross drew three areas of justification for including design as a part of general education. First, design develops in the student innate abilities in solving real-world, ill-defined problems. Second, design sustains cognitive development in the concrete/iconic modes of cognition. Third, design offers opportunities for development of a wide range of abilities in non-verbal thought and communication.

This paper has described the general nature of design education in both elementary and secondary schools, and has described two curriculum initiatives that are attempting to assist both teachers and students come to grips with the many challenges that designing in schools presents. The growing importance of design education for engineers has been described. But as Kimmel, Kimmel and Deek argued, 'a stronger emphasis in problem solving and design will have to be evident in [engineering education] courses if EC2000 is to be met' [42, p. 810–811].

This author has suggested that design education in elementary and secondary schools sows the seeds for engineering education. This is not to suggest that the purpose of school-based design education is preparation for engineering education. Rather, it is suggested that design education is an essential component of the general education of all children. As a result, however, engineering education does not recruit students entirely without appropriate ways of knowing. One challenge for undergraduate engineering education is to identify ways to build on the prior knowledge and experience of students. For example, Kimmel, Kimmel and Deek [42] describe a first-year engineering course in which 'the major assignment . . . is a group design project in which students apply skills previously learned in the class' [p. 811]. To what extent are the 'previous skills' learned in elementary and secondary schools utilized? Are they inventoried? To what extent can these existing skills be used as the basis for further learning?

Hubka and Eder described how design education for engineering should encompass 'two fundamentally different kinds of teaching/learning content: knowledge about the object of designing (the system to be designed); and knowledge about the design process, including methods and abilities of the designer' [27, p. 805]. This has significant resonance with knowledge requirements for students in design and technology, who also require two types of knowledge: knowledge of the problem being tackled and knowledge for the solution. Knowledge of the problem is concerned with 'wickedness', in that it is concerned with the uniqueness of each design task. Each task will have different contextual features that have to be identified by exploration and research: these features cannot be easily obtained from a book or by a web search. Knowledge for the solution can be thought of as composed of (a) procedural knowledge (e.g. being able to use design strategies) and (b) conceptual knowledge (e.g. about the nature, purpose and performance of technical systems and an understanding of design strategies).

The National Academy of Engineering [43], in its report *The engineer of 2020: Visions of engineering in the new century* identified, among others, the following as attributes of engineers in 2020 and beyond: possess strong analytical skills, exhibit practical ingenuity, be creative and have good communication skills. There is significant resonance between this list and one advocated by those conducting research and teaching in the field of design and technology education at both elementary and secondary levels [13].

Nesbit, Hummel, Piergiovanni, & Schaffer [29] describe an innovative first-year engineering course in which students are provided with a 'true engineering experience in the form of design projects which are directly supported by laboratory experiences and lecture topics. . . . The design projects require the *immediate* [authors' italics] application of the laboratory experiences and lecture topics . . . and concurrent math/science/writing courses'[29, p. 435]. This is conceptually similar to the Support Tasks/Design and Make Activity model used in both the Elementary Science and Technology project and Young Foresight. Nesbitt *et al.* [29] also describe how each project is structured to reflect the world of engineering outside of the university. For example, students work in teams to solve problems that are open-ended (ill-structured), require a creative response, and require effective communication skills between team members and teams. There is considerable resonance between this curriculum model and Young Foresight.

Retention in engineering courses is often a concern [44, 29]. According to Elata & Garaway, a leading cause of attrition is the traditional focus in introductory undergraduate engineering courses on mathematics and physics, which 'students . . . regard . . . as just another hurdle on the way to graduation because they fail to see their relevance. Many students become frustrated because instead of getting the practical engineering training they anticipated they are overburdened by theoretical material' [44, p. 566]. The authors go on to say that 'many students . . . once they begin their studies . . . realize that they lack a clear understanding of the actual work of the engineer' [44, p. 566]. Furthermore, 'the concepts [students] are learning in their math and science courses seem abstract, disconnected, and irrelevant' [29, p. 435]. How could the design skills learned in elementary and secondary school courses be integrated into 'theoretical' courses in order to increase retention? Students who have completed curriculum activities such as EST or Young Foresight will have learned to make design decisions. They will have the requisite knowledge, skill and understanding required to design and make a product in response to an identified need or want. They will enter undergraduate engineering programmes full of enthusiasm for creative activities and with the expectation of more of the same. If disappointment with engineering is to be avoided, then it will be important to build on this fund of novice knowledge and experience.

CONCLUSION

In his now famous public address given at the 1955 autumn meeting of the National Academy of Sciences entitled *The Value of Science*, Richard Feynman suggested that when students arrive at the university, it 'is too late for them to get the spirit [of science]' [45, p. 244]. Is this true for engineers and engineering? Is the arrival at university too late for students to 'catch onto' and understand the importance of design and designing? If so, then perhaps the time has arrived when all levels of design education must join together to participate and collaborate in developing Harrison's continuum of design education for engineers.

Engineering has traditionally drawn its students from a mathematics and science background; specialized, mainly convergent thinking subjects. Yet the tacit knowledge that young people develop before this age and the creativity and divergent thinking skills that they have acquired and developed as part of design and technology education are as important to the future of the engineering profession as the highly articulated theoretical understanding of control systems, materials and structures that are regarded as its traditional foundations.

This paper has shown that many elements of a design education continuum exist. Earlier sections of this paper described how design education has become a central component of elementary and secondary school practice. At undergraduate engineering level, many equally exciting changes are occurring. Educating students to become capable of designerly thinking, that is, students who can intervene creatively in the made world to improve the quality of life, must be a shared objective of all involved in design education. It will be these students who become a design literate public, what Baynes [2005] refers to as 'consumer/designers'. A 'design education continuum' calls for close collaboration between educators at all levels. After all, some of these consumer/designers will become engineers.

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