Redefining Engineering Education:

The reflective practice of Product Design Engineering

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INTRODUCTION

Prior to 1987 the prevalent view on the educational basis of professional engineering practice could be summarized in three parts, as follows:

- Acquisition of basic science knowledge (e.g. Physics, Mathematics)
- Acquisition of applied science knowledge from which routine problem-solutions are derived. (e.g. Mechanics, Materials)
- Acquisition of specific skills to support practice (e.g. engineering drawing, computing)

Schon [1], however, argued that the above view led to a situation where '*practitioners are problem solvers who select technical means best suited to particular purposes*'. This raises the following question '*When a problematic situation is uncertain, technical problem solving depends on a prior construction of a well formed problem - which is not in itself a technical task*'.

The ability of experienced professional practitioners [2, 3] to deal with uncertain, conflicting and often unique problem situations suggests a '*professional artistry*' and know-how that are both difficult to enunciate. The required knowledge is revealed only in the action of doing; it is thinking while doing. Schon terms this professional activity '*Reflection-in-Action*' and advocates that students must learn '*a kind of reflection-in-action that goes beyond statable rules*'. To achieve the above he suggests two modes of operation within a teaching environment:

- Telling and listening
- Demonstrating and imitating

The first mode of operation is familiar to all who have followed an engineering education, the second mode is perhaps less familiar, requiring the following two main learning modes:

- Follow me
- Joint experimentation

The first of these learning modes, *Follow me*, requires the tutor to demonstrate how to, for example, design something followed by imitation by the student. The student doesn't have to understand exactly what is going on at the time, rather they have to accept that with practice will come appreciation and understanding.

The second learning mode, *joint experimentation*, requires tutor and student to work together on solving an open-ended problem [4] that is new to both of them. The student must feel confident enough to make suggestions and to criticize those made by the tutor. In this environment the tutor must be robust and willing to admit that they may not know the answer to the problem.

Schon is also clear that, in order for the above modes of operation and the specific learning modes to be effective in developing *reflection-in-action*, an appropriate learning environment and educational culture must be developed and support the curriculum. He refers to this environment as a '*reflective practicum'*.

It was against the above background of educational thinking that the M.Eng./B.Eng. degree program in Product Design Engineering was conceived and nurtured.

EDUCATIONAL MODEL

In October 1987, the Department of Mechanical Engineering, at the University of Glasgow, and the School of Design at Glasgow School of Art embarked on a new four-year degree program that would address many of the educational issues promoted by Donald Schon. This initiative was led by Professor Brian Scott (Mechanical Engineering) and Professor Dugald Cameron (Head of Design, now Director of Glasgow School of Art).

The new degree program was novel in that it was a collaborative effort between two different educational cultures possessing common aim of seeking to bridge the perceived gulf between engineering and product design as well as to fuse cultural and technological design influences. The educational aim of the program was, and remains, to produce a body of young engineers whose main strength will lie in their capacity for creative synthesis and whose primary task will be the design of engineering and consumer products.

A pilot group of eight students were selected to initiate the program that has now grown to an annual intake, in the first year, of some thirty-five high quality students many of whom would not otherwise choose to pursue an engineering degree program.

Philosophy

The philosophy behind the degree program was to approach the practical activity of design from a standpoint that balances technical, manufacturing and creative aspects so as to achieve imaginative solutions to human needs for products in world markets. To this end the Department of Mechanical Engineering acts in concert with the School of Design to create an integrated and educationally stimulating environment where both creativity and innovation can blossom [5]. It achieves the desired integration by bridging between mechanical engineering and industrial design with a view to creating one model of a *reflective practicum*.

Structure

The degree structure (Table 1) was based on an accredited B.Eng. model that had as one of its aims " *that design be a continuous thread running through the teaching*" [6]. In practice this delivered a structure that required students, by the end of their four years of study, to have spent approximately half of their time acquiring engineering design knowledge and skills. The balance of their time being spent exercising and extending their knowledge within both directed and open-ended design activity projects.

Educational Environment

This consists of a design studio environment providing the focus for design activity which, in turn, acts as the main justification for the acquisition of engineering 'core' knowledge and skills and to develop *reflection-in-action*. The expectation being that graduates will be professionally prepared to fuse technical and cultural design issues offering the medium to long term potential of beneficially influencing the design quality, and commercial success, of manufactured products [7].

The course consists of lectures, seminars, practical workshop sessions and laboratories integrated with studio-based (Figure 1) design project activity. This core is enhanced by the contribution of visiting lecturers and tutors from industry and academe providing a varied and complementary perspective on engineering design issues. In short, the aim is to create an educational environment that supports rather than inhibits real learning [8]. It should also enable creativity to blossom [9].

Figure 1, Design Studio Environment

Industrial support and influence

The creation of a *reflective practicum* must include robust and appropriate links with industry. The Product Design Engineering program achieves this via the involvement of industry in design activity throughout all years of study but with particular emphasis in years 4 and 5. Industrial linking includes sponsorship of projects, industrial placements and design studio tutoring of students. The program also benefits from the input of five, Royal Academy of Engineering, Visiting Professors in the Principles of Engineering Design. These professors are senior engineers from a diverse range of successful companies. Each brings a unique perspective of the principles of engineering design and provides a practical context for design decision making.

An additional dimension to industrial support is found in the number of companies prepared to permit access to their design and manufacturing facilities during student foreign field trips. Each year students from the 4th year undertake a visit to a center of excellence. Previous destinations have included Boston, San Francisco, New York, Milan, Stuttgart, Munich, Amsterdam and London. These visits afford the opportunity of witnessing at first hand the approach, to design, taken by different cultures. This breadth of appreciation is, in the authors' view, an essential element in developing the *reflective practitioner*.

Curriculum

The first two years contain the same accredited engineering subject material as the mechanical engineering program but also incorporates an additional integrative design activity element. This element also provides for the acquisition and practice of basic design skills and then moves towards the development of creative and speculative characteristics within the students.

Table 1. Degree Program Structure

	B.Eng./M.Eng. in Product Design Engineering					
	Year 1	Year 2	Year 3	Year 4	Year 5	*Total Hrs.*
Design Activity	150	150	200	400	400	***1300***
Engineer in Society	50	50	50	20	20	***190***
Engineering Subjects	290	325	275	125	125	***1140***
Engineering Applications	25	80	25	50	50	***230***
Engineering Skills	50	50	50	50	50	***250***
Year Total Hrs.	**565**	**655**	**600**	**645**	**645**	**3110**

Year 3 sees the introduction of unique taught subject courses. These subjects were introduced in order to develop the engineering knowledge of the students as well as to accelerate the acquisition and development of design skills over that which would be achieved if only design activity projects were employed. Each taught subject is formally examined. This has presented the examiners with the challenge of constructing exam questions requiring the application of design skills to provide solutions. The design activity in year 3 moves the students towards real-world problem solving, often in conjunction with industry. This industrial focus is reinforced with an industrial placement undertaken at the end of the academic year and a staff/student foreign field trip to a center of design excellence.

The fourth and final year of the B.Eng. program, as well as the fourth and fifth years of the M.Eng., provide students with the opportunity to pursue an individual project. The project can be undertaken with industrial partners or the subject of the project may reflect a particular interest of a student. The project is augmented by advanced study in materials technology, design systems, human factors, mechatronics, design management and history of design. The aim being for the student to demonstrate their grasp of the design process and their ability to apply their engineering design knowledge and skill to uncertain, unique and conflicting problems in a professional manner. In short, have they developed the professional artistry of the reflective practitioner?

An important theme running throughout the program is the need to communicate design ideas effectively to everyone involved in the process. This includes the designers need to externalize ideas so that they better understand the problem and the proposed solution. An ability and confidence in sketching is an important skill for Product Design Engineers.

Design Representations

Students, who initially possess a range of drawing ability, are exposed to a wide range of techniques to support design representation. They are encouraged to embrace techniques that work for them and which reflect their professionalism. Sketching (Figure 2) has a special place within the range of techniques. Indeed, during the earliest stages of design, the sketchpad is used to express and represent ideas and has been referred to, by Schon, as the medium of reflection-in-action. He suggests that through drawing, designers construct a ‘virtual world’ where the drawing reveals qualities and relations unimagined beforehand. Sketches are representations which will often allow the designer to ‘try out’ a new idea on paper, quickly and cheaply. Schon also notes that while drawing can be rapid and spontaneous, its residual traces are stable and can be subsequently examined by the designer at his or her leisure. Despite its importance in the design process, the sketch has a perceived low status. The true value of the sketch is often hidden by the modesty of the designer responsible [10]. Though it is one of the most tangible artifacts produced directly during the conceptual activity [11], Schon’s ‘stable traces’ may not be kept for subsequent use. Typically, when a project is completed, early exploratory drawings are often destroyed and cleared away to make room for the next job [12]. The permanence of the sketch has perhaps been overlooked in favor of its spontaneity. The sketch also possesses the potential to act as both facilitator and recorder of creative acts thereby presenting opportunities for improved evaluation and the re-stating of a problem [13].

The ability to represent design ideas in two dimensions is clearly flexible and quick. It is equally important that the ideas find expression in three dimensions (Figure 3) to enable evaluation, testing and validation of the design intent. Students are therefore increasingly exposed to a range of design support technologies.

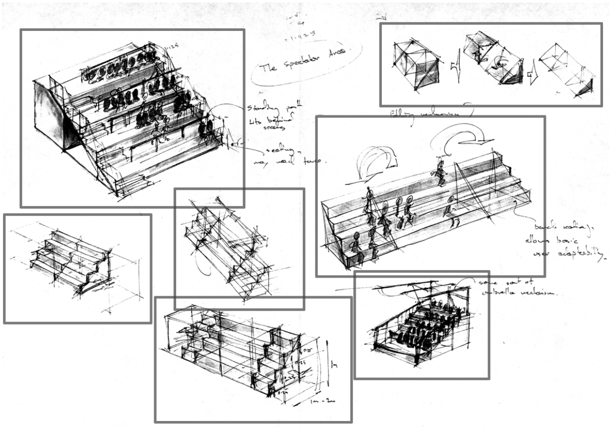

Figure 2, Design Concept Sketches for Portable Grandstand

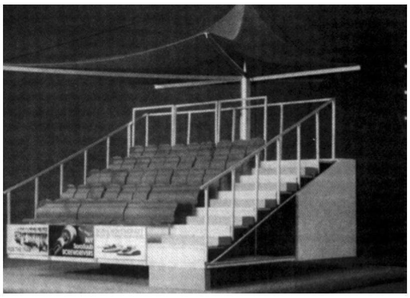

Figure 3, 3D Model of Portable Grandstand

Supporting Technologies

The reflective practitioner in engineering design needs to be familiar with the tools supporting their activity. Increasingly important are the technologies supporting reduction in design time scales whilst improving the capacity of designers to evaluate and validate their design intent [14]. These technologies include Rapid Design and Manufacture (RDM) of which there are two aspects that students are encouraged to embrace:

- The technologies themselves, Stereolithography, Selective Laser Sintering, etc. and how the process characteristics of each of these technologies make them more suitable for particular applications.

- How the technology can be used to its best advantage in support of design methodologies.

In addition to RDM, students become familiar with the following complimentary technologies:

- Conventional Modeling Techniques
- Reverse Engineering
- 3D CAD Solid Modeling
- Data Communications and Visualization
- Data Manipulation

International Connections and Influences

For any educational initiative it is important that it is constantly evaluated to ensure that it continues to be generically developed to meet the changing demands of the profession and society. With this in mind the Product Design Engineering program has collaborated, over the past few years, with like-minded institutions from the UK, Holland, Germany, France, Denmark, Norway, Finland and Eire, to develop understanding about Engineering Design education. Initiated via a European funded ERASMUS ICP network, and led by Philips Gerson of the Hanzehogeschool, Groningen, the group has grown and developed to provide mutual support through activities such as:

- Intensive weeks - where third or fourth year students from different countries/cultures meet to discuss common issues and to tackle an open-ended design project.
- Student exchanges
- Staff teaching exchange
- Student field trips

Throughout this period industrial collaboration has been significant both in terms of supporting student projects but also in hosting and contributing to discussions about the nature of engineering design.

One important outcome from our collaboration, to date, has been the recognition of the culturally different approaches taken towards the practice of engineering design and the development of a curriculum for engineering design education. Equally the different factors driving the design approaches adopted by industry have been highlighted. This has led to the group making a proposal, for funding under the LEONARDO scheme, to undertake a formal research project aimed at examining the different approaches taken by industrially supported student design projects in all countries within the collaborating group.

This project [15] is termed Open Dynamic Design (ODD) and has the following objectives:

- To observe the different engineering design project models being used within the partner institutions and to look for common elements and variations that lead to differing perceptions of success as judged by the students, the staff and the industrial partners.
- To compare and contrast the academic approach with the practice of industry.

The anticipated deliverables form this project include:

- A technique and method selection tool for industry
- A unified basis for engineering design curriculum development

To meet the specific research challenges mentioned above the following research methods will be used:

- **The expert approach**, checking the experience opinion of key people on the logic and weight of context factors and the influence of tools on results.

- **The participant as observer**, the engineers and students involved in the selected industrial projects are asked to assess the nature or 'level' of the context factors in their particular situation
- **The interview by one observing body**, to examine ways of applying technology, techniques, control methods etc. The full extent of context factors must be addressed.
- **Proof of theory by experiment of (positive) change,** deliberately change factor/method combinations to check predicted/expected positive effects.

In addition to the European perspective an international view and influence has been maintained. This has been achieved via visits and discussions with:

- Staff at MIT and Stanford in the USA
- The University of the Witwatersrand, Johannesburg, South Africa
- The University of Adelaide, Australia
- Swinburne University of Technology & Swinburne School of Design, Australia

The latter case has resulted in the implementation of a new successful degree program. In August 1996 staff from the course were invited to the Swinburne University of Technology in Melbourne, Australia to assist with collaboration between the School of Design and the School of Mechanical and Manufacturing Engineering. The assistance comprised a two week visit to meet with staff, explain the aims and rationale behind the Glasgow model, guide curriculum and timetable design and subsequently help with the preparation of accreditation documents for the Institute of Engineers, Australia. Initial indications are that students with above average entry qualifications and a higher proportion of women are attracted to the course.

MEASURES OF SUCCESS

It is all very well to describe a new educational initiative and to make bold claims for its influence and success but how is the success to be measured and monitored? The approach adopted within Product Design Engineering is to evaluate the degree program aims and objectives against qualitative review criteria: industry review, peer review and graduate/undergraduate review. The overall reputation of the program can further be measured against the quality and number of applicants. As will be evident in the following descriptions of each review criteria there are a number of sources of data that require to be triangulated into a single measure. Criteria are, at present, given equal weighting.

Industrial review

Industrial review comments are obtained from a number of sources, including:

- Industrial liaison committee
- Industrial project sponsors
- Industrial placement and work experience providers
- Industrial employers of graduates
- Visiting Professors from industry and other industrial tutors
- Industrial comment after final year viva presentation
- Request from industry to provide training courses for experienced engineers.

Peer review

Comment on the degree to which objectives are being met are obtained from peers via:

- External Examiners comments

- Visiting academics comments
- Adoption of our educational model by other institutions
- Status of educational model among Faculty members
- Degree Program accreditation by Institution of Mechanical Engineers
- Williams Holdings Prize for innovation in teaching and learning in higher education

Graduate/Undergraduate review

Student feedback on individual subject courses taught within the degree program is obtained at the end of each term via an anonymous evaluation form. This is augmented by feedback after every design project. Further review is achieved via a staff/student consultative committee. Graduate comment is obtained through the completion of questionnaires after a few years experience in industry. This is particularly informative as it provides a unique insight into the extent to which educational objectives are reflected in the practice of a diverse range of industries.

Quality of student applicants

An important measure of the success of an educational program is the quality of the applicants. This is measured using two scales:

- Points score on application
- Number of applications

A growing issue in engineering education is the gender mix achieved within educational programs. Product Design Engineering has been particularly successful in this regard with the gender mix growing to the current position whereby 60% of the intake are male and 40% female.

CONCLUSIONS

The diversity of problem being addressed and the quality of the resulting work produced by the Product Design Engineering students bear witness to the success of the educational model employed and to the educational theory underpinning the model. It also demonstrates the need to staff such an educational model with people who have experience of the professional practice being taught and who are robust enough to deal with the rigors of the design studio environment. The Product Design Engineering program has been fortunate in this regard over the past ten years. The students emerging from this program of study demonstrate an enhanced capacity to problem solve and to deal with the uncertainty of product development and they exhibit a capacity for professional practice whilst displaying professional skills that will support them in whatever career they wish to pursue. The feedback from industrial employers supports the above view. The students are seen to be ready from day one to contribute to the profitability of their employing company.

It is the intention of this paper to provide the educational community with an example of what can be achieved as a result of breaking down traditional educational barriers. Time alone will tell if the Product Design Engineering degree program has succeeded in redefining, or should it be rediscovering, the true nature of engineering education.

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