New Directions in Engineering Education:
Developing Creative and Responsible Product Design Engineers

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Abstract

New product development has been described as an industry that requires the integrated skill sets of both Industrial Design and Mechanical Engineering. However, designers typically lack the technical depth and analytical skills of an engineer, whilst engineers lack the design acumen and user-centred approach of the industrial designer. This lack of cross-discipline synergy may result in inefficiencies and missed opportunities, and be detrimental to the new product development process.

Design and engineering faculties now recognise the need to train graduates who are more suited to cross-disciplinary roles in product design. One such approach is the new engineering discipline of Product Design Engineering (PDE), an engineering qualification that results from the integration of industrial design and mechanical engineering curriculum. The pedagogical integration of these disparate professions has potential to lead a new direction in engineering education, by fostering creativity, introducing vital social and environmental agendas, expanding learning opportunities through design project-based learning and developing human-centred design acumen.

This research examines the product design industry and identifies key graduate attributes for engineers engaged in new product development. It discovers critical areas of concern in engineering education, establishing the need for new engineering pedagogy. It also explores the integration of design into engineering curricula as a means to enhance the product design capabilities of engineering students.

The research then investigates the emergence, impact and relevance of the Product Design Engineering pedagogy, as an appropriate response to both the expectations of new product development industries, and the educational reform mandated by global engineering regulatory organisations. This research, as the first examination of the Product Design Engineering paradigm, represents an original contribution to knowledge in respect to identification, analysis and documentation of an emerging global trend in engineering education. It makes an argument for the inclusion of design and creativity curricula in engineering education and validates Product Design Engineering as an appropriate response to industry and regulatory expectations.

Acknowledgements

Firstly, I wish to thank my research supervisors, Professor Ajay Kapoor (of the Faculty of Engineering and Industrial Sciences) and Dr Gavin Melles (Faculty of Design), for their wisdom, mentoring and encouragement during my candidature. They have both brought individual and highly valuable perspectives to the research and their clear direction has ensured an efficient and enjoyable journey.

I would also like to thank the former Dean of the Faculty of Engineering and Industrial Sciences, Professor John Beynon for both his support of the Product Design Engineering program, and his encouragement of this research.

Special thanks also to all of my colleagues at Swinburne University of Technology, in particular those whose teaching and curriculum innovation contributes directly to the success of product design engineering; Dr Soullis Tavrou, Dr Christine Thong, Stephen Langdon, Dr Blair Kuys, Kate Bissett Johnson, Mark Strachan, and Dr Simon Jackson.

Above all, I wish to thank my wife Susan and daughter Portia for their patience and understanding during the candidature.

Ian de Vere

Declaration

This thesis contains no material which has been accepted for award of any other degree or diploma, except where reference is made in the text of the thesis. To the best of my knowledge, this thesis contains no material previously published or written by another person except where due reference is made in the text of thesis and where the work is based on joint research or publications, discloses the relative contributions of the respective workers or authors.

Name: Ian de Vere

Signed:

Dated:

Ethical Statement

I certify that the human research used to develop data for the thesis entitled "New Directions in Engineering Education: Developing Creative, Human-Centred Engineers for Roles in New Product Development" has been conducted with approval and under the conditions required by the Swinburne Research Ethics Committee.

This research involved three human research projects:

- SUHREC Project 2009/168: Survey of Product Design Engineering Curriculum and Pedagogy – approved 19 August 2009
- SUHREC Project 2010/038: Survey of Product Design Engineering Graduates – approved 16 April 2010.
- SUHREC Project 2010/042: Interview of employers of Product Design engineering graduates – approved 16 April 2010

All human research conformed to Swinburne and external regulatory standards, including the National Statement on Ethical Conduct in Human Research.

I verify that all conditions pertaining to the ethics clearance have been properly met with respect to informed consent, and secure data use, retention and disposal.
CD-ROMs and hard copies with all material in relation to the three specific ethics clearances have been submitted to the Head of Research, Faculty of Engineering and Industrial Sciences, Swinburne University of Technology and have been securely stored in the faculty according to the regulations.

Name: Ian de Vere

Signed:

Date:

Contents

Figures and Tables

Publications List

The following papers represent findings and outcomes from this research which were published during the research in peer-reviewed journals, a book, and within conference proceedings. They are available through the Swinburne Research bank at http://researchbank.swinburne.edu.au.

2012

de Vere, I., Melles, G., Kapoor, A. (2012) Sketchfest: emphasising sketching skills in engineering learning. *The 14th International Conference on Engineering and Product Design Education (E&PDE12,* Artesis University College, Antwerp, Belgium

2011

de Vere, I., Melles, G., Kapoor, A. (2011) Developing a Drawing Culture: New Directions in Engineering Education, *International Conference on Engineering Design ICED11*, Copenhagen, Denmark.

de Vere, I., Kapoor, A., Melles, G. (2011) An Ethical Stance: Engineering Curricula Designed for Social Responsibility, *International Conference on Engineering Design ICED11*, Copenhagen, Denmark

2010

de Vere, I. & Melles, G. (2010) Integrating 'designerly' ways with engineering science: a catalyst for change within product design and development. in SILVA, A. & SIMOES, R. (Eds.) *Handbook of Research on Trends in Product Design and Development: Technological and Organizational Perspectives,* IGI Global.

de Vere, I., Melles, G. & Kapoor, A. (2010) Product design engineering - a global education trend in multidisciplinary training for creative product design. *European Journal of Engineering Education*, 35 (1), 33-43.

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2009

de Vere, I. (2009) Developing creative engineers: a design approach to engineering education. *Creating a Better World, the 11th International Conference on Engineering and Product Design Education (E&PDE09)*, University of Brighton.

de Vere, I., Bissett Johnson, K. & Thong, C. (2009) Educating the responsible engineer: Socially responsible design and sustainability in the curriculum. *Creating a Better World, the 11th International Conference on Engineering and Product Design Education (E&PDE)*, University of Brighton, UK.

2008

de Vere, I. (2008) Managing Industry Collaboration: Providing an Educational Model in a Client-Led Project, *the 10th International Conference on Engineering and Product Design Education conference(E&PDE08),* Universitat Politčcnica de Catalunya, Barcelona, Spain

Introduction

Background

> *"The increasing competition for consumer markets and the growing awareness of the importance of design for the market has led to reinforcement of the view that successful design can only be accomplished by an integration of the skills of both engineering and industrial designers." (Cross 2000, p. 203)*

New product development requires a synergy of both industrial design and mechanical engineering, and it is preferable that both the design and engineering aspects of a product are addressed concurrently. However, designers typically lack the scientific depth and technical skills of an engineer, and engineers lack the creative exploration and user-centred approach of the industrial designer. Fry (2006) notes that whilst industrial designers typically look for new innovative contexts (often broadening the scope of the problem), engineers are more comfortable working with defined parameters to achieve closure. Whilst it would be preferable to have a product designer with the skills of both disciplines, it is more common for designers and engineers to collaborate on design projects, despite the misalignment of skills in problem solving and creativity. This lack of cross-discipline synergy may result in inefficiencies and missed opportunities, and can be detrimental to the new product development (NPD) process.

However the need for multi-disciplinary skills in product design and development as noted by Cross, is being addressed by both design and engineering curricula that serve to integrate the skills of both professions, albeit in different ways. Both design and engineering faculties now recognise the need to train graduates who are more suited to cross-disciplinary roles in product design and development. Many design faculties throughout Europe offer the design-led curricula of Industrial Design Engineering (IDE), which originated at Delft University more than forty years ago (Visscher 2009), in which the creative process of industrial design is supplemented with engineering knowledge.

Engineering faculties have also responded to the need for a creative and human-centred design engineer with double degree (B.Eng/B.Des) programs, design majors (T-shaped learning models) and more recently in the United Kingdom and Western Europe with engineering curricula such as Product Design Engineering (PDE).

Although Product Design Engineering originated in Glasgow in 1987, there has been an increase in industry interest and new course development in the last 10-15 years, and thus it is now emerging as a global 'engineering' alternative to the intent of the IDE model and a new and distinct engineering discipline.

The PDE program is unique as its concurrent integration of two distinct professions (Mechanical Engineering and Industrial Design) offers a 'parallel' inter-disciplinary learning experience that differs significantly from the double-degree or T-shaped education model typical in engineering education. Rather than building the foundations of the key profession first (e.g. mechanical engineering) then overlaying additional disciples (e.g. a design major) at an advanced stage (often in the third year), PDE curricula usually integrates design and engineering learning from the first year of study. This delivery aims to facilitate inter-disciplinary methodology, and thus a more flexible and adaptable approach to engineering practice.

It is important to clarify the difference between Industrial Design Engineering and Product Design Engineering, as although both disciplines attempt to educate cross-disciplinary professionals for new product development, there are critical differences. The IDE programs are 'design' courses which typically result in either a Science degree (BSc/MSc) or Design (BDes/MDes) qualification. However the PDE courses are 'engineering' degrees that generally result in engineering (BEng/MEng) qualifications, and global professional recognition by engineering regulatory bodies.

The intent of Product Design Engineering discipline appears not to supplement engineering with remedial design skills. Rather the curriculum aims to produce inter-disciplinary synergists who are capable of operating effectively in either discipline, but whose main contribution is to integrate the activities of both engineering and design. More importantly, the curriculum appears to address the specific needs of the new product development (NPD) workplace.

It has often been noted in product design and development, that neither industrial designers nor mechanical engineers possess the full complement of required skills, such as technical and engineering ability, creative design skills and understanding of user needs. This lack of synergy may result in professional rivalry, misunderstanding and poor communication between collaborating disciplines, to the detriment of the design process and the resultant product outcome. It appears that the PDE model differs from other engineering disciplines, forsaking depth in some areas of engineering theory to instead focus on user-centred design, creativity and interdisciplinary design practice, as appropriate for new product development.

As Product Design Engineering focuses on preparing students for employment in the product design and development arena, it challenges the validity of industrial design as an independent profession and redefines the role of engineering in product design. It also appears to address requests from industry employers and engineering academics for "a new generation of adaptable, flexible, well rounded and innovative professionals" (Stouffer et al. 2004, p. 10), with the capacity for "having unusual ideas, tolerating the unconventional and seeing unexpected implications" (Cropley et al. 2000, p. 207). Multi-disciplinary curricula such as Product Design Engineering (and to a lesser extent IDE) have the potential to respond to demands for engineering graduates who are creative designers, and can "think broadly across disciplines and consider the human dimensions" (Grasso et al. 2007, P. B8).

In addition, these new engineering curricula, with their integrated design syllabus, have the potential to lead a new direction in engineering education, by introducing critical social and environmental agendas, expanding learning opportunities through experiential (project based) learning, fostering creativity and developing the requisite design acumen. "The purpose of engineering education is to graduate engineers who can design"(Dym et al. 2005, p. 103). It is the inclusion of what Cross defined as 'designerly ways' into the engineering curricula that differentiates PDE from more established engineering programs. The addition of design methodology, with emphasis on human-centred design and creative problem solving appears to have impacted student demographics, the learning experience and the professional practice of this new engineering discipline, as is shown in this thesis.

New product development – a definition

New product development (NPD) describes the process of delivering a new product to market. These products are either stand-alone products or part of an integrated product and service system. Innovation through new product development is central to the manufacturing and service industries. The NPD process involves idea generation, product design and development and detail engineering; activities normally completed through collaboration between industrial designers and mechanical engineers, in response to market research and analysis. Accordingly, product design concerns itself with innovative design solutions that address the usability, aesthetics, ergonomics, performance, marketability and manufacturability of a product typically designed for medium to high volume production. The competitive impetus for this new product development is driven by innovation, new technology, market / consumer expectations and changing social, economic and cultural demographics.

As noted by Cross (2000) the level of complexity of the product determines the degree to which mechanical engineering or industrial design skills are required. For simple products the engineering input may be relatively small, whereas for more complex devices it may be the significant contribution (refer to Figure i.1).

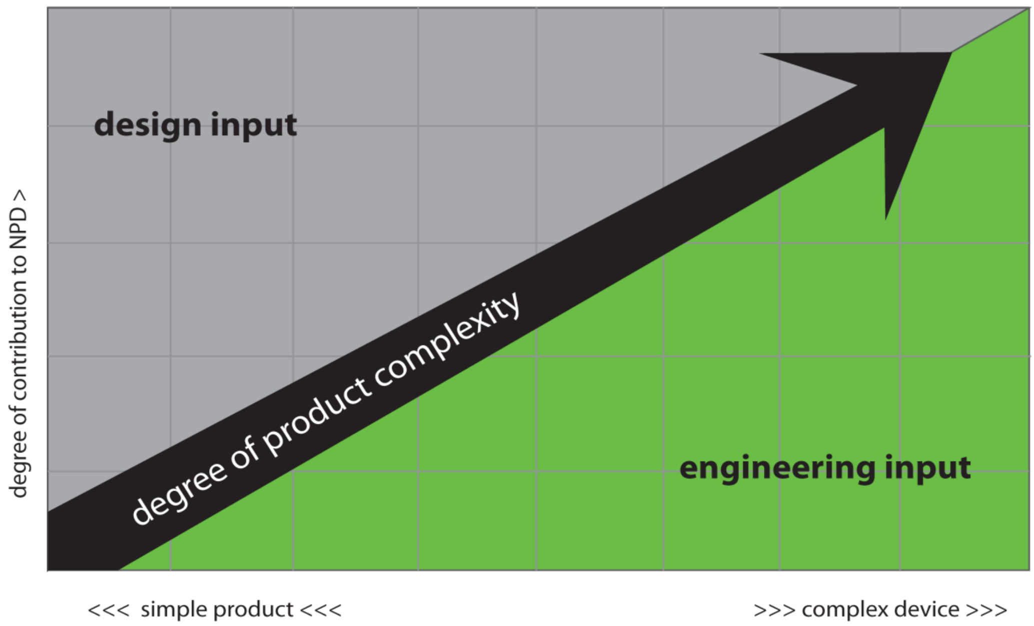

Figure i.1: design and engineering contributions in new product development - engineering input increases as complexity increases

In this context, a simple product is one that requires little technical or engineering intervention in the design resolution or design for manufacture stages, whereas a complex device may be determined by engineering or technical innovation, or complex manufacturing, or be part of a system of interdependent components. Yet regardless of product complexity, input from both disciplines is required, as the development must converge on all aspects of design (including aesthetics and user-product interaction) and engineering (technical and manufacturing resolution).

In the context of this research, product design and new product development refers to the creative activity that humanises technology through design of consumer products, specialist medial / bio-medical equipment, furniture, electronic, automotive and other products and associated services through either demand-pull or technology-push innovation. The scope of product design is typically less broad than that of engineering design and is concerned with the development of innovative, market-driven user-centred products rather than the provision of highly complex systems (Cross 2000).

Positioning of the research

This research examines the need for integration of industrial design and mechanical engineering curricula to develop more suitably trained engineers for roles in new product development.

It identifies the critical educational requirements and engineering practice-based agendas that require an educational response, including:

- low female representation in engineering,
- the need for an emphasis on sustainability,
- the potential of socially responsible design for societal contribution,
- training in user-centred design
- fostering creativity and innovation,
- the need for greater design skills (including sketching),
- better preparation for professional practice in new product development, and
- improved skills integration and synergy within product design teams

The research then investigates the emergence, impact and delivery of the Product Design Engineering pedagogy, in regard to the expectations of industry and the educational reform mandated by global engineering regulatory bodies. This new engineering discipline is examined and the Product Design Engineering curriculum is assessed as a more suitable model of engineering education, in the preparation of graduates for roles in new product development.

As the author has co-coordinated the Product Design Engineering program at Swinburne University of Technology in Australia for many years, that course is used extensively within this research as an example of typical Product Design Engineering training, and its curriculum is examined in detail through the supporting case studies that illustrate critical educational agendas.

Potential researcher bias

The role of the author as the Design Coordinator of the PDE program at Swinburne presented the research with unique and unfettered access to curriculum materials and student project outcomes, student and graduate statistical data and direct contact with alumni and their employers. This enabled the research to gain a thorough understanding of the transference of curriculum intent to real world employability and to measure of the effectiveness of the Product Design Engineering curriculum.

However the author's role as program leader suggests that neutrality in regard to this research would be difficult, and accordingly efforts have been made to ensure unbiased reporting. The Swinburne PDE program is managed by two Program Coordinators, from different faculties (Design and Engineering), under the academic direction of Discipline Leaders, in collaboration with an Industry Advisory Panel. Whilst the researcher has responsibility for the 'design' curriculum of the program, the program results from cross-faculty collaboration and is not solely directed by the author. As it was hoped that this research would lead to improvements in the curriculum, it was essential that the researcher assumed a critical and detached viewpoint. However, to alleviate any potential for researcher bias, which could eventuate due to the closeness of the author to the subject, a decision was taken to base the research on global instances of product design engineering rather than the

Swinburne example. Care has been taken to utilise global data and examples to reinforce the text, except where specific examples of application of theory were necessary. Accordingly, the detailed case studies, which utilise Swinburne examples, are separated from the main text of the thesis and positioned as appendages to the text. In addition, the positioning of the researcher on the design side of the curriculum may have led to a conflict of interest in regard to assessing engineering versus design aspects of multidisciplinary education. However the Supervisors of the research were aware of the potential for researcher discipline bias and the research was directed through quantitative techniques, including triangulation to achieve result convergence, to address these concerns.

The early comparative study of international PDE curricula informed the initial stages of this research and defined the later investigations. The subsequent examination of critical curriculum agendas was led by pattern revealed though the curriculum benchmarking survey rather than by the Swinburne curricula. Whilst findings are typically supportive of the discipline, this was not unexpected as anecdotal evidence from industry prior to the research was the trigger for the investigation.

Research objectives

This research, in its evaluation of the Product Design Engineering paradigm, aims to understand the implications of this model of engineering education, in particular to:

- identify graduate attributes expected by engineering regulatory organisations,
- examine PDE as a new engineering discipline with a distinctive skill set,
- benchmark international PDE programs, evaluate curricula and identify this commonality of purpose as a new direction for engineering education,
- measure the impact of this engineering discipline against existing product design disciplines; in particular industrial design and mechanical engineering though surveys of alumni and interviews with industry employers,
- understand the benefits and shortcomings of multidisciplinary design-engineering curricula, and
- identify curriculum developments in Product Design Engineering that may benefit learning in other engineering disciplines.

Research questions

What graduate attributes must engineering curricula develop to prepare engineers for roles in new product development?

Can the integration of design and engineering curricula enhance the product design capabilities of engineering students?

Is the Product Design Engineering curriculum an appropriate response to the current and future needs of new product development industries?

Scope and justification of inquiry

This research is the first significant investigation into the relatively new engineering discipline of Product Design Engineering, especially in an Australian context.

Whilst PDE is well known in the UK where such courses have existed since 1987, Swinburne Product Design Engineering is the only course within Australia that integrates design and engineering into a single curriculum. As such, it represents an unambiguous opportunity to examine the impact and influence of new engineering curriculum on the local product design and development arena.

Feedback from industry had indicated that Swinburne Product Design Engineering graduates have made a significant contribution to product design environments (particularly in Melbourne) with operational procedures and role allocation amongst product design teams changing in response. It appeared that the PDE graduates were:

- intruding on roles traditionally occupied by industrial designers,
- valued as creative and human-centred design engineers, and
- a viable alternative for businesses employing engineering and design staff.

This was worthy of further investigation and justified the research.

This research identifies critical graduate attributes for engineers engaged in new product development (establishing the need for new engineering pedagogy), investigates the new engineering discipline of Product Design Engineering, suggests it as a viable solution, and then analyses its impact on new product development.

It is acknowledged that many of these attributes are developed in other curricula (such as Industrial Design), however it is the packaging of these skills and agendas within a curriculum that has up to 60 percent mechanical engineering content, that is unique to the PDE curriculum, and produces graduates with distinctive skill sets.

Research Methodology

The research methodology employed a case study approach, where different aspects of the topic and stakeholder perspectives were separately addressed. As the research specifically examined critical skills and agendas for engineers engaged in new product development and the associated curriculum responses, the research used a 'between methods approach' and methodology was adapted as necessary. As a result, chapters focus on specific curriculum aspects and the literature review is embedded throughout the thesis to support specific arguments. This is reinforced through a 'combined method study' of all stakeholder perspectives including course directors, graduates and employers, using surveys and interviews for qualitative and quantitative data collection. Although sample sets are small in some instances, this is a result of the 'purposive sampling' technique used where specific predefined groups were targeted, and the small number of institutions and courses relevant to this study. Central aspects of the curriculum are illustrated by individual case studies to inform the practical aspects of the teaching process. Whilst the research encompassed a broad investigation into global examples of Product Design Engineering, situational necessity resulted in a closer investigation of the Swinburne University PDE program. As the candidate had direct access to Swinburne curriculum delivery methods and student project outcomes these form the basis of the supporting case studies, found at the end of Chapters 2, 3 and 4, which serve to illustrate the practical application of theory into teaching practice.

In this regard, the research is potentially limited in its ability to make broad conclusions and generalisations as the some of the data regarding graduate skill sets, career pathways and industry relevance is constrained to only Swinburne University alumni and their employers, rather than global data sets. However the findings of these areas of primary research appear to be representative of the discipline as they correlate with evidence provided by other institutional course leaders.

Gathering of Evidence

The need for new engineering pedagogy to train graduates for roles in new product development was identified through industry expectations, regulatory requirements of engineering bodies (such as Engineers Australia, SARTOR and ABET), government education agencies (such as the Tertiary Education Quality and Standards Agency, and the Australian Qualifications Framework) and the deliberations of leading engineering academics as revealed in the literature review. Whilst it is not unusual for engineering bodies to campaign for new pedagogy, engineering accreditation panels are typically cautious of new curricula especially when traditional engineering content is reduced to allow new learning, unless there is an increase in industry employability or a focus on new vocational pathways.

This research proposes Product Design Engineering as a possible solution; a new engineering discipline with appropriate graduate attributes for employment in NPD. This proposal is validated through qualitative and quantitative data that has been generated through a variety of research methods, including:

- international PDE curriculum benchmarking exercise (academic surveys),
- an on-line survey of Swinburne alumni (graduate survey), and
- semi-structured interviews with Australian employers of PDE graduates.

The resultant data validates the impact and relevance of the PDE pedagogy.

The international **curriculum benchmarking survey** canvassed the views of PDE course coordinators, examining course structure and content and accreditation, student demographics, the integration of the design and engineering course components, graduate pathways etc. It aimed to find curriculum commonality and to define critical agendas, trends and distinctions across a wide range of courses and countries. The examination and analysis of curricula concerned fifteen courses across seven countries from the UK, Europe, Australia, the USA and South America.

The **graduate survey** asked alumni to evaluate their educational experience and measure their abilities against requisite industry needs, compare their roles, skills and attributes against those of other NPD disciplines (e.g. industrial designers and mechanical engineers), suggest curriculum improvement and discuss industry awareness of this new engineering profession in regard to career progression.

The **employer interviews** enabled the researcher to understand and evaluate the impact of the pedagogy in terms of critical industry relevance. In these semi-structured interviews, employees from a range of industries (including design consultancies, automotive, manufacturers of industrial and consumer products, and bio-medical products), discussed PDE graduate strengths and weaknesses, evaluated their employability and organisational contribution (compared to industrial design and mechanical engineering graduates), and discussed creativity and design skills. These results represent industry validation for the Product Design Engineering curricula and highlight the contribution of these graduates to their chosen industries.

Research outcome

The research described in this dissertation represents an examination of the Product Design Engineering paradigm, its curriculum delivery and agendas and its impact on the new product development workplace.

It identifies (through curriculum benchmarking) that Product Design Engineering is gaining worldwide recognition as a distinct engineering identity, with broad appeal to females and those with a creative disposition, who may not typically choose an engineering career, without lowering entry requirements or the level of engineering curriculum complexity. These courses are attracting high quality students who can deal with the demanding standards of engineering education, including technical expertise, science and mathematics, whilst developing design and creative acumen. Research evidence (resulting from surveys of alumni and interviews with employers of Product Design Engineers), points to a significant contribution in new product development and revised roles and responsibilities for engineering in new product development. As such this research represents:

- an original contribution to knowledge in respect to identification, examination, analysis and documentation of an emerging global trend in engineering education,

- a coherent and cogent argument for the inclusion of design and creativity curricula, and societal/environmental agendas in engineering education, and
- validation of Product Design Engineering as an appropriate response to industry expectations of engineers in new product development.

It should be noted that, whilst the integration of design, creativity and responsibility has been more successful in engineering education within the UK, in an Australian engineering context Product Design Engineering is a unique curriculum model.

Thesis format and presentation

The author has published widely during the research. The nine papers which contribute to this research, include a paper in a leading engineering journal, a chapter in a handbook of trends in product design and development, and presentations at several international design and engineering education conferences (refer publications list).

This was a deliberate and calculated approach to the research. By publishing throughout the research, the author sought to actively engage with both industry and educational communities to facilitate collaboration and comparison between curricula and engineering educational intent. It was also intended that the papers provoke discussion of critical, but often neglected agendas in engineering curricula such as sketching and creativity, sustainability and socially responsibility and human-centred design, and present alternative pedagogy to the wider engineering academic community for discussion and feedback.

The structure of this dissertation reflects this process. These papers have been revised and updated, then incorporated into chapters. This is noted where relevant at the start of each chapter and in the section introductions. The chapters that derive from peer reviewed papers describe the curricula in detail, examine the different agendas driving the learning journey (e.g. creativity, sustainable design and social responsibility, industry collaboration) and evaluate its impact on engineering education and professional practice.

To avoid content overlap and maintain narrative flow throughout the thesis, publications from this research have not been included as originally published. Rather the text of individual chapters draws from the content of the published papers, revised and restructured as appropriate. The original papers are available on-line through the Swinburne Research Bank, at http://researchbank.swinburne.edu.au/.

Thesis Structure

The thesis consists of eight chapters which firstly establish the need for new engineering pedagogy to address the requirement of roles in new product development and identify specific attributes required by engineers to operate effectively in that arena. Product design engineering, a relatively new engineering discipline is then examined as a potential solution for training engineers for new product development and examined as a global trend in new engineering curricula. Critical attributes and education and professional agendas are then examined in detail before a validation process that analyses the potential of Product Design Engineering to contribute to, or enhance new product development processes.

The positional chapters are supported by evaluation and validation chapters that examine and benchmark and determine significance to industry and the professional impact of the Product Design Engineering curriculum and profession. Due to the nature of this research, the construction of chapters deviates from the traditional sequence of thesis structure. As the literature reviews were an ongoing process relating to specific areas of the research, the traditional literature review is incorporated throughout the thesis as befits its role in supporting the arguments and positions presented in the earlier publications and the subsequent chapters.

Whilst the main text of the thesis draws from global Product Design Engineering curricula, chapter content is supported by four case studies which contain a detailed examination of specific curriculum and delivery examples from Swinburne University of Technology. These case studies serve to illustrate how the key skills, graduate attributes and learning agendas can be addressed in engineering curricula.

Chapter One, *The Need for a New Engineering Pedagogy* introduces the need for collaborative, multidisciplinary product design teams that integrate the skills of both industrial design and engineering, a requirement noted by both the Cox Review (Cox 2005) and the Design Council UK (2010). This reinforces the need for a new engineering professional, specifically trained for new product development. The issues and challenges confronting product design are discussed, as are the requisite graduate attributes and critical agendas for engineers engaged in NPD. The need for creative problem solving and design ability supported by environmental and societal conscience is explored. The Product Design Engineering (PDE) curriculum is introduced as an engineering discipline with potential to contribute to the education of engineers for roles within new product development. The global emergence of PDE is discussed and program intent compared.

Chapter Two, *Examination of Global PDE Curricula,* charts the outcomes from an extensive worldwide examination of PDE-style curricula. Engineering courses that purport to integrate design into the curricula were considered for evaluation. The Industrial Design Engineering programs typically found across Europe were not included as they are better described as design courses with engineering content rather than fully accredited engineering degrees.

Program Coordinators at twenty-seven international institutions offering Product Design Engineering (or similar) programs were approached to participate in an on-line curriculum benchmarking survey. The curriculum survey examined the integration of engineering and design and the development of key graduate attributes such as creativity and user-centred design, the inclusion of critical issues such as sustainability and socially responsible design, industry engagement and graduate pathways. The responses identify a commonality of purpose and help to categorise this global trend in engineering education. Chapter 2 concludes with Case Study 1: *Examination of the Swinburne PDE Curriculum,* in which a typical Product Design Engineering program provides a detailed insight into this new engineering discipline.

Chapter Three, *Fostering Creativity and Emphasising Sketching* examines the need for more creative engineers, the importance of a design-focussed curriculum and differing methods of fostering creativity, including open-ended problem solving, sketching and innovation, project based learning, and multi-disciplinary education. It argues for drawing as a facilitator of not just investigative and exploratory processes (ideation) but also as a primary explanatory or instructional tool, and for technical and functional resolution, detailing the emphasis placed on creativity and design within the PDE curriculum. Chapter 3 concludes with Case Study 2: *Developing a Sketching Curriculum* which examines curriculum initiatives that aim to develop a drawing culture and enhance creativity amongst PDE students.

Chapter Four, *Ethical Engineering* proposes that engineers extend their professional responsibilities from service provision to serving the interests of not just business but also global communities through socially responsible, ethical and sustainable design. The chapter discusses the importance of real world projects that develop understanding and empathy and ability in social design, and ensure that graduates understand the potential impact of their professional activities and their potential to contribute to the betterment of global communities. The chapter concludes with Case Study 3: *Developing Social and Sustainable Design Practice in Product Design Engineering*; a study of the ethical curriculum in the Swinburne PDE program.

Chapter Five, *Collaboration with Industry* discusses industry engagement (in the final year capstone project) and examines barriers to successful collaboration with industry, from both a learning and design outcome perspective. The benefits of real-world constraints, professional design validation, and enhanced career pathways resulting from client-led projects are considered against managing expectations, realistic workloads and achieving the required learning objectives. The chapter concludes with case Study 4: *An Industry-Led Capstone Project* where the collaborative alliances formed between final year students and industry partners in the final year 'professional project' are examined in detail.

Chapter Six, *Evaluating Design and Problem Solving Ability* discusses the need for enhanced real world problem solving ability to better prepare students for the practice of engineering. Project exercises that develop creativity, sketching and design skills and instil confidence with design exploration, ambiguity and uncertainty are validated by the results of a comparative evaluation that compared Product Design Engineering students with mechanical engineers when faced with both open-ended and constrained problems. The results justify the inclusion of design content within engineering curricula to develop problem solving abilities, and prepare engineers for employment in new product development roles.

Chapter Seven, *Graduate Skills and Career Pathways* analyses data from a survey of Swinburne PDE alumni. Graduates were asked to evaluate their educational experience and measure their abilities against requisite industry needs, compare their attributes against those of industrial designers and mechanical engineers, and discuss industry awareness of the Product Design Engineering profession.
The survey results identify the typical roles and responsibilities of Product Design Engineers, their skills and attributes, and point to a graduate cohort satisfied with their educational journey, endowed of appropriate skills for employment in new product development, and keen to contribute to the new engineering community of Product Design Engineering.

Chapter Eight, *Industry Relevance* documents the results of interviews with employers of Swinburne Product Design Engineering graduates. Semi-structured interviews were conducted with employers from differing industries including design consultancies, manufacturing R&D and specialist biomedical companies. This chapter describes this process and analyses the findings with regard to strengths and weaknesses, employability, creativity, organisational contribution, and skill sets.

The results provide evidence of the contribution of the PDE program to new product development, with broad industry acceptance and appreciation of graduates unique multidisciplinary attributes.

Chapters 2, 7 and 8 provide quantitative data that validates the research and identifies an engineering graduate cohort, whose skills and attributes match the expectations of the new product development industry, engineering regulatory bodies and leading engineering academics.

Chapter One: The need for a new engineering pedagogy

1.1 Overview

This chapter draws from the text of a book chapter which was published in the IGI Global, Business Science Reference book, Handbook of Research on Trends in Product Design and Development: Technological and Organizational Perspectives:

> de Vere, I., & Melles, G. (2010). Integrating 'designerly' ways with engineering science: a catalyst for change within product design and development. *Handbook of Research on Trends in Product Design and Development: Technological and Organizational Perspectives. A* Silva, & R. Simoes (Eds.), IGI Global. ch.10. (pp. 173-194)

The chapter also draws from two peer-reviewed papers; a journal paper originally published in the European Journal of Engineering Education,

> de Vere, I., Melles, G. & Kapoor, A. (2010) Product design engineering - a global education trend in multidisciplinary training for creative product design. *European Journal of Engineering Education,* 35 (1), 33-43

and a conference paper presented at the 2nd International Conference of Design Education hosted by University of New South Wales through collaboration between the Faculties of Engineering, Built Environment and the College of Fine Arts.

> de Vere, I., Melles, G., Kapoor, A. (2010) Product design engineering: interdisciplinary pedagogy integrating engineering science with 'designerly ways', *ConnectED 2010 – 2nd International Conference on Design Education,* University of New South Wales, Sydney

These publications, which resulted from the initial stages of the research were co-authored by my PhD supervisors Dr Gavin Melles (Faculty of Design) and Professor Ajay Kapoor (Faculty of Engineering and Industrial Sciences).

The chapter initially examines the interdisciplinary collaboration of the design and engineering professions in product design and development, the issues confronting product development teams, and identifies changing roles and responsibilities for engineering. As a result, a new palette of skills for engineers engaged in new product development, including a greater emphasis on design, creativity and sketching and open-ended problem solving, is defined. Also evaluated is the potential for design engineers to make a greater contribution to global societies through sustainable design and socially responsible design processes.

This chapter serves to introduce the research though examination of the new product development environment, investigating the challenges for engineering curricula in educating for that industry, and identifies critical graduate attributes for engineers employed in product design environments.

The relatively new engineering discipline of Product Design Engineering (PDE) is introduced as curricula that directly responds to the needs and agendas of new product development, and is proposed as a possible solution for training creative and human-centred engineers for roles in that environment.

The emergence of this new engineering discipline is charted, as is the global spread of similar integrations of engineering and design curricula. Key educational agendas are identified including social responsibility and sustainability, design creativity, sketching, and problem based project work; curriculum inclusions which develop appropriate graduate attributes for employment in new product development roles.

Product Design Engineering is shown as an example of the potential outcome of teaching ‘designerly’ thinking to engineers; the emergence of a new engineering graduate specifically suited to the current and future needs of new product development.

1.2 Introduction

Product design is the convergence point for design and engineering thinking and practices. New product development teams are multidisciplinary environments which require designers and engineers to collaborate harmoniously. This integrated approach enables new synergies and additional service provision, which leads engineering into fresh areas of professional activity but challenges traditional engineering education.

The characteristics of product design now require a greater focus on sustainable design, socially responsible design and design for need. Opportunities exist for design teams to make a positive contribution to the welfare of global communities whilst advancing technologies that support sustainable development (Melles et al. 2011). In this changing environment, engineers engaged in product design must assume new responsibilities and a greater role to achieve successful product realisation.

As the roles and responsibilities of product design teams are reformed, so too are their professional composition. The single discipline purity of the traditional industrial design consultancy has evolved into a multidisciplinary team, where designers and design engineers collaborate to provide an extended palette of services. Accordingly, product design teams require an integrated and collaborative approach in environments of understanding and mutual appreciation. The product design and development process is enhanced by these new synergies between engineers and designers, as is the progression of the engineering designer into new areas of professional activity.

Whilst design engineers have always been an integral part of the product development process, their roles have traditionally been confined to working within constraints and defined parameters on technically complex products or to achieve closure to the product realisation stage. But now, emerging trends in manufacturing and revised professional responsibilities require design engineers to have a greater role in product design and development, even in the conceptual design stages.

To be effective in new product development, engineering graduates require new skills, including creative design ability, a thorough understanding of the societal and environmental impacts of their professional activities, and a human-centred and responsible approach. These attributes traditionally have not been addressed by engineering curricula, but are evident in new multidisciplinary engineering curricula, such as Product Design Engineering. These interdisciplinary engineering graduates, who are trained to be proficient in both design and engineering roles, are well positioned to make valuable contributions to new product development.

This new engineering discipline results from the integration of two traditionally disparate professions; mechanical engineering and industrial design. It responds to the need for interdisciplinary professionals and a greater participation in design teams by engineers conversant, indeed accomplished, in all areas of the product design and development process. These new engineering pedagogies support the changing role of the engineering designer and are catalysts for significant change in product design and development through greater team synergy, interdisciplinary understanding and communication. "Times of great flux call for those who can cross disciplines, who can see and understand the big picture" (Akay 2003, p.148).

1.3 The role of design

Design is a fundamental building block of innovation and a critical enabler of competitive advantage. Product design is essential in addressing the challenges that modern societies face in the 21st Century, whether it be enabling the delivery of technological, scientific or medical advances, empowering communities, mobilising public opinion, or simply improving the product experience (Design Victoria 2008).

It is evident that there are many challenges facing the new product development (NPD) industry as we move through the 21st century. These range from the decline of local manufacturing and the impact of a global economic downturn, to new opportunities afforded by emerging markets, and the integration of new disciplines. Sustainable practice and socially responsible design will continue to redefine the product design industry, which must take responsibility for its activities and show leadership as drivers of change and enablers of technical and sustainable innovation.

The fortunes and growth potential of the product design industry in Western nations are closely allied to the manufacturing sector, an area of recent considerable upheaval and changing alliances (Design Council UK 2012). The transfer to offshore manufacturing has had unprecedented impact in the design sectors of many countries, as have the competitive forces of a global economy and the reduction in Government protection of local industries. Many product design environments have witnessed a rationalisation of product lines, a reduction of local content and a shift in outsourcing towards 'design and supply' contracts.

In response product designers must take responsibility for their destiny through business diversification, entrepreneurship and the creation of new opportunities through flexible and adaptable approaches. New production technologies (including additive rapid manufacture) may assist to reduce reliance on the established manufacturing sector (as a sole source of revenue); in turn this will lead to greater diversification of services into new sectors, including interdisciplinary activities which are solution, rather than market focussed. "The designers' unique contribution is translating and creating values" (Press et al. 2003, p. 50).

Socially responsible design initiatives and sustainable solutions are imperative and offer design teams a diversity of new opportunities. This will need to be complemented by design-led initiatives as product design teams redefine and create new avenues of activity, and respond to societal needs on a global basis. Kel Dummet of Sustainability Victoria has suggested that "a new economy is evolving and it needs products and services that have been designed to eliminate environmental impacts" (Design Victoria 2008, p.59).

As manufacturing industries adjust to a changing economic and social environment, new markets are emerging with diversified consumer behaviour and expectation. It is therefore essential that new product development teams develop interdisciplinary attributes that successfully integrate design, engineering, management and marketing in a flexible milieu of understanding and respect, with a high level of creativity and consideration for environmental, societal, cultural and economic demands. Martin Temple, Chair of the EEF (Engineering Employers' Federation) states in the Design

Council UK's multi-disciplinary design education report, that "The economic goal of generating more wealth from new science demands multi-disciplinary teams of designers, engineers and technologists designing around the needs of customers" (Design Council UK 2010).

Product design needs to be reformed to allow societal contribution to be made through new directions of activity. The key issues of sustainability, social responsibility, design for need, global distribution of design and manufacturing processes, emerging markets, aging demographics and shifting economic power will be the focus of the next generation of product designers and design engineers, who must be sufficiently informed and skilled to lead the inevitable industry reform.

In Australia, the Design Victoria (2008) report *"Five Years On: Victoria's Design Sector 2003-2008", (through a survey of 340 design service providers and 1253 businesses)* identifies design as making an essential contribution of economic growth, yet the report also recognised that graduates lack appropriate skills, including business acumen and production and manufacturing knowledge; a trend apparent in both the design and engineering sectors.

Industry feedback supports this observation of poor graduate ability. Employers in the new product development industry have expressed dissatisfaction with recent graduates, reporting that industrial design graduates are too conceptual with limited technical understanding, whilst mechanical engineers lack creativity and design skills and are not well prepared for the specific demands of that industry (refer chapter 8, section 8.7). Clearly as industry reform will be led by the next generation of designers and engineers, the challenges faced by industry must be met firstly at an educational level through revised, industry relevant and progressive curricula.

It is important to define the roles and responsibilities of future product design teams and understand the challenges they face and their potential to contribute. Product design teams must respond to the emergence of new technologies and societal demands including the shift from passive to active society, the transition from consumer to producer, and the rise of hyper-individuality (Frey 2007), in addition to dealing with the impact of global development on the environment. Educators cannot hope to foresee all of the challenges that their graduates will face throughout their careers; however curricula must prepare engineers who can respond to significant change. This will involve new curricula that develop flexible, adaptable and responsible engineers who are lifelong learners and creative problem solvers. Futurist Thomas Frey describes it as "Preparing humanity for worlds unknown, preparing our minds for thoughts unthinkable, and preparing our resolve for struggles unimaginable." (Frey 2011, p. 23)

Tertiary education should be the foundation of improved and redefined professional outcomes for product design. New multidisciplinary curricula such as Product Design Engineering appear to respond directly to the needs of the new product development industry and address societal and environmental concerns. The integration of disparate disciplines (industrial design and mechanical engineering) has the potential to facilitate professional synergies, and thus, efficiencies in the product design and development process.

Multidisciplinary training in both design and engineering will develop Product Design Engineers who are cognisant in all aspects of the product's 'function-aesthetic-experience' and understand the importance of product innovation. The challenges of future product design and development may be alleviated through teams which include 'integralists' (Eekels 1987) who can articulate the product vision in an collaborative environment devoid of traditional professional rivalry.

1.4 The need for synergy in product design teams

In Engineering Design Methods, Nigel Cross notes "that successful product design can only be accomplished by an integration of the skills of both engineering and industrial designers" (Cross 2000, p. 203) This trend is evident both in product design consultancies and in the manufacturing sector where there is increased demand for engineers who can operate effectively in a variety of environments within global multidisciplinary teams. Engineers, particularly those in product design and development, are now expected to be creative, flexible and adaptable, responsible and human-centred designers. “In this evolving world, a new kind of engineer is needed, one who can think broadly across disciplines and consider the human dimensions that are at the heart of every design challenge” (Grasso et al. 2007, p. B8). Hong *et al* support this, stating that “for design engineers to participate effectively in this new environment (integrated product development), they should possess an expanded set of capabilities” (Hong et al. 2005, p. 64)

However, it has been observed that the boundaries between the design and engineering professions can inhibit both innovation and successful product realisation, particularly in the product design and development milieu. “These two mindsets often clash as one seeks to broaden the scope of the problem, while the other is working to achieve closure.” (Fry 2006, p. 4)

Conflict between disciplines has been common in product design and development, where differing professional approaches can destabilise the progression of design ideals. A long-standing cultural conflict exists between designers and engineers, one that can be traced to the foundation of their approach to problem solving and design. Fry (2006) defines industrial designers as “looking for new contexts and opportunities for innovation” whilst engineers “predominately work to define a set of parameters and target values up front that would define a specific, successful solution within a narrow range” (p. 4)

It is important to acknowledge that the approach of engineers to design activity results from the attitudinal emphasis of their education. Mechanical engineering curricula is directed by professional regulatory and accreditation organisations (e.g. Engineers Australia, UK Engineering Council, ABET etc), and industry expectations that require graduates to be prepared for a wide scope of engineering practice (including the design of large and complex systems) with a strong emphasis on scientific theory and mathematical modelling.

The fundamental elements of the engineering process are analysis and synthesis, testing and validation, and resultantly many engineering curricula offer limited exposure to the creative design process. This can mean that engineering graduates are often inexperienced in open-ended problem solving and fearful of the uncertainty of the design journey. Engineers trained only in the 'science' and 'methods' of engineering can be hesitant to engage in intuitive or creative processes that may lead to an unexpected outcome.

This may not be of concern in many engineering endeavours where the operational parameters are known and outcomes quantified and predetermined, but within the field of new product development, it may result in logistical and cultural difficulties.
"Effective product development requires integration to occur at the conceptual level." (Hong et al. 2005, p. 75)

The absence of cohesion or synergy between engineers and designers can lead to misunderstanding, a lack of appreciation, and subsequently, professional distrust and discord within the NPD team. Professional disparity between engineers and designers can impact on a concurrent, cross-functional and integrated process resulting in inefficiencies and critical problems detrimental to successful product realisation. (Koufteros et al. 2001) To facilitate developments in product design and development, the disparities between the professions must be addressed through engineering and design educational programs that emphasise design, encourage creativity and innovation, resulting in improved cross-disciplinary communication, understanding and mutual appreciation.

It is evident that product development roles require "a new generation of adaptable, flexible, well rounded and innovative (engineering) professionals" (Stouffer et al. 2004, p.10) However innovation and creativity does not readily emerge from typical engineering process. To be creative, one needs to seek the unexpected through a process of divergent thinking.

It has been observed that engineering design and industrial design follow differing methods; "convergence is at the core of the engineering process ...divergence is at the core of the industrial design process" (Fry 2006, p. 3). Cross (2001) observed that scientists problem-solve by analysis, whereas designers problem-solve by synthesis. The designers approach is user and solution-focussed, frequently intuitive and divergent; whereas convergence is at the core of the engineering process. The designer’s constructive and often intuitive approach uses non-verbal thought and communication, translates abstract requirements into concrete objects, and contributes to the solution-focussed approach that designers use to solve ill-defined problems. (Cross 2001)

It is therefore apparent that to develop creative design engineers, their educational experience must not only include rational applications of science, but also experience in open-ended problem solving and familiarity with what Cross (2001) describes as ‘designerly ways.’ ‘Designerly ways’ suggests a way of thinking that is common in designers, but which differs significantly from the techno-scientific analytical approach used by engineers.

Whilst it is essential that engineering programs develop the necessary knowledge, skills and rigour appropriate for the profession, it appears that engineering curricula could benefit from the inclusion of design pedagogy (or designerly ways), to develop creative problem solving skills early through education, rather than later in the workplace.

Solving future challenges (e.g. climate change, an ageing population and the need for more sustainable energy and food production) “will demand new approaches to innovation, new combinations of skills, and teams of people who can combine their disciplines and expertise in new ways” (Design Council UK 2010, p. 9)

1.5 Combining Design and Engineering Thinking and Practice

Product design is “a generic term for the creation of an object that originates from design ideas – in the form of drawings, sketches, prototypes or models – through a process of design that can extend into the objects production, logistics, and marketing” (Slack 2006, p. 6). The product design process involves stages of product planning, concept design, product development, product styling and detail design (Baxter 1995). Owen (1998) has suggested that product design is more concerned with ‘making’ and aesthetic and cultural judgements than is typical for engineering.

However, many texts treat industrial design's input into product design as a single stage in a multistage product design process. Ulrich and Eppinger (2004) in their textbook "Product Design and Development", devote a chapter to Industrial Design (ID) where they examine the role of ID in the product design and development process. In this, they endeavour to quantify the utilisation of industrial designers and the timing of their involvement in the development process, claiming that "the ID process is a sub-process of the product development process" (p. 202).

Whereas the Industrial Design Society of America (IDSA) defines industrial design as "the professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer," Ulrich and Eppinger appear to consider this to be too broad, instead noting that industrial designers "focus their attention on the form and user interaction of a product" (p.190).

They define two different outcomes and related processes for product design and development; technology-driven products whose core benefit is based on its technology or ability to perform a technological task, and user-based products where the functionality of the user interface, aesthetic appeal, brand identity and marketability are critical. They state that "typically, ID is incorporated into the product development process during the later phases for a technology-driven product and throughout the entire product development process for a user driven product" (p.202), the inference being that engineering is responsible for all other stages.

In this, Ulrich and Eppinger have (unintentionally) identified one of the fundamental concerns in new product development; that 'technical' projects have no early industrial design consideration, limiting the contribution of design agendas to product schematics. When Industrial Design processes are integrated late in the project, (at a convergent stage of development) the product's technical specification has often already been established. This negates the contribution of design expertise in product-user interaction, ergonomics, sustainable design and socially responsible design (SRD) and aesthetics, combined with understanding of user needs, market requirements and product differentiation, to influence product scoping and positioning.

It is important that these elements are not retrospectively added to a rigid technical specification, when product parameters are defined and existing constraints may restrict innovation, but integrated throughout all stages of the product design and development process. A creative, user-centred approach greatly informs the problem framing process, and results in a more appropriate and targeted product specification. Therefore it is important that the early stages of new product development projects (regardless of whether it is for user or technology led products), involve personnel who are not only technically competent, but also user-centred, with a creative divergent thinking approach and appreciation of aesthetics and product identity.

Figure 1.1 (following) shows an example of typical product design and development process (for a user-driven product) showing separated and overlapping areas of responsibility for industrial designers and engineering designers. In a technology driven product, the ID engagement would commence at a later stage, once the technical specification had been developed and tested, with the designer's role mostly limited to component packaging.

There is also a relationship between marketing, industrial design and mechanical engineering in new product development. Marketing typically provides the 'trigger' for the NPD process through a range of activities, including identification of the market niche and the initial product need, project and product definition and the initial briefing. Problem framing and identification of user needs, and the resultant product design specification tend to result from collaboration between the marketing, design and engineering teams (Ulrich et al. 2008).

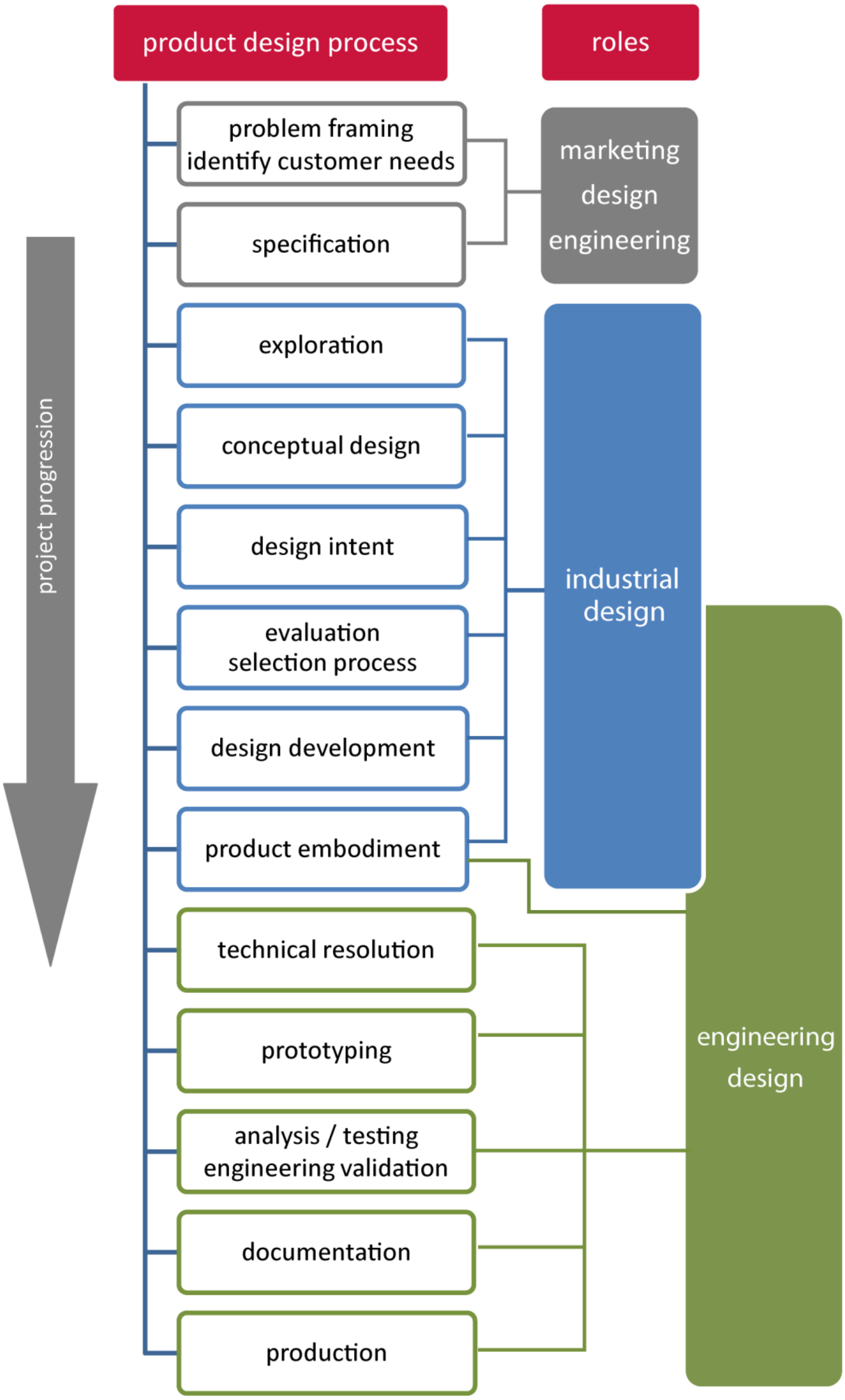

Figure 1.1: example of a product design process (for a user-driven product) showing typical areas of responsibility for industrial designers and engineering designers
(image source: Ian de Vere, with reference to the design process models of Pahl and Beitz and the Verein Deutscher Ingeniere (VDI) guidelines)

It is apparent that the designer is typically responsible for the creative 'front-end' processes and engineering is occupied with the more technical product realisation (back end) of the product development process. However it is just as important for considerations of manufacturing (e.g. design for assembly) to be included early in the planning and design stages, and for user-centred design to address not only the needs of the end user, but also production, transportation, and installation personnel.

Poor product design decisions can adversely affect market success and the efficiency of internal processes. Manufacturing costs, assembly schematics, quality control, product to market lead-times, market appeal and overall product success are vulnerable to a lack of synergy between designers and engineers and poor team structure at critical design decision stages. It is evident that both production and user/market concerns should be at the forefront of all product embodiment decisions. This suggests the need for product design staff that can operate across both engineering and design disciplines boundaries.

It is evident that there is a need for multidisciplinary engineers who can integrate 'designerly ways' into the practice of engineering to achieve two key objectives:

- to drive user-centred and creative design philosophy in the planning stages of new product development, particularly in technology driven products where industrial designers may not normally be included in the discussion, and
- to ensure technical and production considerations during planning and ideation stages of user-led products

Product design is usually taught in design schools as a specific incarnation of industrial design or taught as a component of the mechanical engineering curriculum. However there is increasing global recognition of the need for greater synergies between industrial design and engineering training, but this shift would, nonetheless require educational innovation and change.

One response to the need for greater synergies between engineering and industrial design has been the development of Industrial Design Engineering programmes, particularly in the UK and Europe (e.g. TU Delft, TU Twente, TU Eindhoven). These courses are typically 'design' focussed, with the inclusion of engineering course content to broaden graduate attributes and knowledge. Industrial Design Engineering (IDE) is a combination of the technical and the form-giving/design worlds; a systematic approach to integrated product development, which considers human and consumer factors as well as market research. A graduate in Industrial Design Engineering can operate in the field of product design as an interdisciplinary designer.

A more engineering response has been the development of the Product Design Engineering (PDE) discipline, which integrates 'designerly' thinking throughout accredited engineering courses. PDE is an interdisciplinary 'engineering' programme that integrates industrial design into mechanical engineering curricula, whilst maintaining engineering knowledge and competency. These new engineering curricula have resulted in a new engineering discipline with multidisciplinary skills appropriate for roles in new product development.

1.6 The skills of design engineers and industrial designers

Whilst industrial design is concerned with product identity, external design, aesthetics, user-product interface and user experience, design engineers are concerned with design of the product internals, product performance and functionality using, "...scientific principles, technical information and imagination in the definition of the mechanical structure, machine or system to perform pre-specified functions with maximum economy and efficiency." (Fielden 1963, p. 8)

It is apparent that engineering design is preoccupied with realising 'product-working functionality' whilst industrial design is responsible for 'human-using functionality' of the product (Kim et al. 2010). Bates and Pedgley (1998) articulated the differing skills sets of industrial designers and design engineers noting that the design engineer has expertise in areas of mechanical design, materials/manufacturing and electronic design, whilst the industrial designer has proficiencies across a wide range of skill sets such as artistry, mechanical design, marketing and psychology.

Figure 1.2 is a reproduction of Bates and Pedgley's diagrammatical comparison of skills between engineering design (at left, represented in green) and industrial design (at right, in blue).

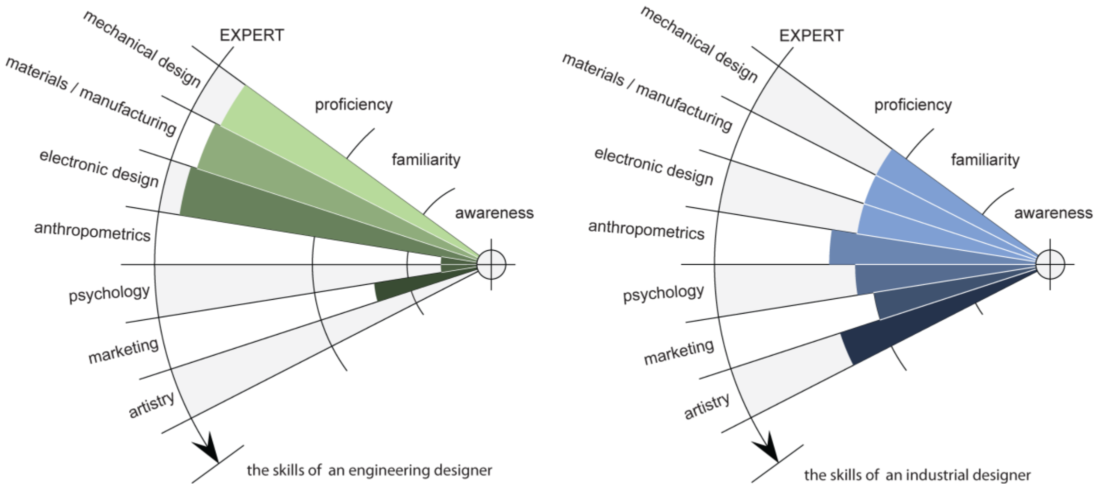

Figure 1.2: comparison of the skills of engineering designer and industrial designer (image source: reproduced from the original illustration by Bates, DJ and Pedgley, OF., 1998)

This reading of the demarcation between design and engineering is valuable as a comparison of representative skills, although it is curious that the industrial designers whilst credited with a wide skill-set, are not acknowledged as having 'expertise' in any area of product design activity.

1.7 Key skills and critical agendas for NPD training

It is apparent as the product design and development industry evolves to meet new challenges, that its participatory engineers will require an enhanced skill set and new knowledge. In this regard, engineering regulators and industry are encouraging curriculum agendas to develop new graduate attributes.

ABET's Engineering Curricula 2000 requires engineering graduates to have:

- an ability to function on multi-disciplinary teams,
- an understanding of professional and ethical responsibility,
- an ability to communicate effectively,
- the broad education necessary to understand the impact of engineering solutions in a global, economic*, environmental,* and *societal* context.

Engineers Australia has discussed engineering's contribution to broad social goals through a paradigm shift in sustainability (Hammer 2007), and consequently requires an understanding of the human and environmental consequences of engineering activity (Engineers Australia 1996), and envisions a workplace where "engineering becomes an inclusive profession which values, supports and celebrates the contributions of women in the engineering team" (Engineers Australia 2013)

Global female enrolment in engineering is particularly low, with Julie Hammer (National President of Engineers Australia in 2008) declaring that "We cannot afford to have 50% of the population so under-represented in our profession." (Engineers Australia 2008, p. 1). Whilst this issue is being addressed globally by engineering regulatory bodies though 'Women in Engineering' initiatives, it is also apparent that established engineering curricula is not appealing to young women and that unless engineering faculties respond accordingly with more attractive educational programs, female engineers will continue to play only a minor role in new product development.

ABET in their review of engineering curricula (1998) and the Engineering Council UK (1997) have expressly called for the fostering of creativity in engineering education, whilst a survey of employers by Cropley and Cropley (2000), indicated that up to 75 percent of new graduates were considered (by industry) to be 'unsuitable' for employment because of 'skill deficiencies' in creativity, problem-solving, and independent and critical thinking.

The positions of engineering accreditation bodies, engineering academics and representatives for the new product development industry, point to the need for new curricula that responds to changing societal and environmental needs and market expectations, develops creative engineering graduates suitable for the challenges of 21st century product design, and delivers education that is appealing to both genders. Consequently, new product development engineers will need enhanced graduate attributes, in addition to the existing skills and knowledge, including:

- improved design emphasis (including sketching ability),
- a creative user-centred design approach,
- a socially responsible design philosophy,
- an emphasis on sustainable product design and manufacture,
- advanced open-ended problem solving ability,
- improved gender balance (female engagement in engineering)

1.7.1 An emphasis on design

"Design is a primary function of the engineering profession. Professional engineering education should encourage an applications-oriented framework to the teaching of engineering science material and a greater emphasis on project work of a design nature" (Engineers Australia 2008, p. 4).

Despite calls by engineering accreditation bodies, many engineering faculties have been reticent to incorporate any significant design course components, with many leading engineering academics noting that other areas of the curriculum have dominated the teaching agenda. This concern has been acknowledged by Dym who frustrated by the lack of focus on engineering design, declared "for the last half of this century, mathematics has been the language of design" (Dym 1999, p. 146)

Faculties aim to build a solid foundation of engineering science, but infrequently include design activities that provide opportunities for this knowledge to be applied, especially in the early years. A typical mechanical engineering curriculum contains foundation, technical and management subjects, but design is often limited to machine design and mechanical systems design and CAD-based subjects. Design projects are constrained and limited in scope, and there is a notable absence of divergent thinking and creativity development, which is evident in industrial design curricula through open-ended problem solving and design project-based learning.
"Design should play a larger role in the curriculum" (Dym 1999, p. 146).

Design has always been fundamental to the practice of engineering, and thus should be a key constituent in engineering education. Both Fox (1981) and Cross (2001) have identified that there is an educational justification for design as a means to develop cognitive skills and real-world problem solving abilities.

Without design and creative skills, graduate engineers will continue to be technically competent, but will not be prepared for the practice and challenges of engineering in the 21st century. Yet, as identified by leading American engineering academics, it appears that mechanical engineering curricula continues to focus on the theory-based science model, denying students the learning opportunities afforded by design projects, particularly in the application of engineering science to real world practice (Dym et al. 2005)

"One of the consequences of design-focused education is that students learn that they are applying knowledge in differing forms to serve different ends, which means that they can become fluent translators of engineering languages" (Dym 1999, p. 147). It would appear that design needs to move from the periphery to a more central role in engineering education if we are to graduate innovative and adaptable engineers, and enable more valuable engineering input in the product design process. "Design is the heart of engineering and must be at the core of engineering education. It must be embedded in all four years of the curriculum; it must be an integral part of technical as well as nontechnical courses" (Moore et al. 2003, p. 453)

1.7.2 Fostering creativity

It is implicit that creativity is integral to design innovation, and that design and the fostering of creativity should be the cornerstone of engineering pedagogy. Yet mechanical engineering curricula do not always provide opportunities for students to develop design aptitude or creativity. "Engineering is, by nature, a creative endeavour, but many engineering colleges fail to address this, and end up training engineers for technological task completion" (Pappas 2002, p. 1).

Despite demands from ABET and the Engineering Council UK and other engineering regulatory organisations, fostering creativity in engineering education may not be occurring, or is currently ineffective. An examination of mechanical engineering curricula across a range of universities, fails to reveal significant activity related to the development of creativity, with the exception of leading institutions such as Cambridge, Stanford, MIT etc but rarely extends into undergraduate Mechanical Engineering programs where the majority of engineers engaged in product development are taught. It should be noted that creativity has a larger operational canvas in smaller less complex systems such as in product design, whereas engineering education is typically focussed on educating to address the design of highly complex systems. The commitment of time required to impart engineering science knowledge and technical rigour is understandable, however there appears to be little acknowledgment of the importance of creativity in engineering practice. “Creativity is the essence of engineering. Yet creativity is neither explicitly taught nor promoted in the engineering curriculum” (Santamarina 2002, p. 99).

Creativity is frequently misunderstood, and is often viewed with an element of mistrust, especially by those outside the design community. This is due to creativity being viewed as resulting from ‘ex nihilo’ (something from nothing), rather than from less confronting processes involving structured problems and expected or predefined solutions. However, engineering students must become comfortable with the creative process, and prepared to embrace unexpected outcomes and pursue innovative solutions.

Teaching engineers that creativity involves “a non-linear, unstructured and flexible approach to solving problems and generating ideas” (Pappas 2002, p. 3) can facilitate acceptance and willingness. “Making the strange familiar – accepting creativity as a desirable mindset and attribute of engineers – is a tangible and realisable goal.” (Stouffer et al. 2004, p. 10)

So what is creativity and why is it important in an engineering educational context? Creativity emerges from a divergent thinking process that allows the designer unconstrained exploration, the use of intuition and reflection to respond to a problem with a solution-focussed approach (de Vere et al. 2010). Creativity seeks to generate new, unique and unexpected solutions. This is not just relevant for those engineers engaged in new product development, but also for engineers engaged in complex system design where creativity may emerge through a less structured thinking process and result in improved systems integration, innovative use of materials or processes or an unprecedented solution.

"Creativity is of paramount importance in engineering for it endows one with insight and discipline to seek out and address problems from the boundaries of different engineering disciplines" (Ghosh 1993, p. 113)

It must be acknowledged that many professional engineering tasks consist of working within closely defined parameters, and addressing the stringent requirements of building codes, technical standards, design regulations, standard operating procedures and other conventions. As such, engineering activity can be governed by process, and in this context creativity could be categorised as less than important. However this would be to ignore the contribution of creative processes to engineering innovation throughout history, those instances where engineers have made significant professional advancement through exploration of possibilities outside existing engineering convention.

Without a creative methodology, the potential for engineers to contribute to new product development is limited and products determined by engineering innovation are less likely. Creativity results from a flexible and open approach to problem solving, an approach dependent on confidence and a willingness to take risks and trust intuitive ideas. Typically, these attributes have not been developed through the engineer's education, but have been gained through extensive industry experience.

To adequately prepare graduates for industry, and to enable more innovative engineering practice, creativity should be fostered throughout the learning journey.
One way to achieve this is for curricula to facilitate experience of design problems, in an environment that appreciates unexpected solutions, tolerates failure and nurtures students through the framing and resolution of ill-defined problems.

Felder (1987) notes that creativity can be fostered through exercises that focus on:

- ideational fluency
- poorly defined and open ended problems requiring divergent thinking
- synthesis of material outside normal boundaries
- evaluation – technical decisions vs. social and ethical considerations
- problem finding and definition (not just problem solving)

The development of problem ‘framing’ skills reduces anxiety about unexpected solutions, develops the student’s confidence in their creative potential, and instils a desire for seeking creative and innovative solutions. It is no longer sufficient for students to be engaged in simple problem ‘solving’ activities; experience in the ‘practice of engineering’ must occur through experiential learning projects that allow science to be applied to real world problems.

Engineering education that ignores problem definition may result in graduates who can resolve a technical issue, but who are not solution focussed. Product innovation results not from just solving a problem, but from a explorative and reflective process that seeks a unique solution.

1.7.3 Project based learning – learning through design projects

“Innovation requires creativity. The easiest vehicle for promoting creativity and for developing the student’s decision making ability is the design project.” (Eekels 1987, p. 266)

The application of engineering science to address problems through project-based learning is best applied in the design project, where students respond to a design brief with a resolved solution that can be prototyped and tested against established criteria. The design project, especially in the context of product design (where scale of work and accessibility parameters are manageable), allows students freedom to explore creative engineering solutions. Whereas problem-based learning can identify which solution will work, a design outcome resulting from a project-based learning model can prove that the solution is the most appropriate and best performing.

Developing product design aptitude requires experience; opportunities to learn, to explore, to experiment and to fail. Traditional engineering pedagogy, when reliant on a theory-based scientific model, does not offer many such learning opportunities.

Students are not often challenged to apply their newfound knowledge to the design of product solutions for real world problems; it is more likely that students will be tested on their science through examination and through solution-focused problem solving activities that lead to predetermined outcomes. However, this is not the ideal approach to develop creative and innovative engineering practitioners; but is more likely to result in graduates who readily fixate on the security of known solutions.

On the other hand, a design project-based curriculum is 'learning in action' where students learn theory, and develop creativity and design experience through project-based or experiential learning processes. Students are required to explore the limits of their imagination, to push the boundaries of technology, processes and materials, to investigate the possibilities and extend their own potential.

The design project affords opportunities for the application of the known (the science of engineering) to be applied to the unknown; often resulting in an unexpected solution. In the design project, every brief will result in unique, original outcomes from every student; there are no correct or incorrect answers, instead the project facilitates pathways to creative design solutions, and new ways of learning. This learning model is constructive, participatory and problem driven; an exemplary pedagogical model of 'learning by doing' and is the most effective way to educate creative engineers for new product development.

In the following student design examples, it is evident that the design project has provided the opportunity for global PDE students to apply their engineering knowledge to real-world problems through an explorative and experimental design process resulting in innovative and unprecedented product solutions. These examples illustrate the application of sound engineering practice in a human-centred content and demonstrate significant learning occurrence.

Figure 1.3 shows an innovative vacuum moulding die, developed by a PDE student from Brunel University, that is easily and quickly reconfigurable adding rapid response and flexibility to manufacturing environments. In Figure 1.4, a student from the collaborative PDE program jointly offered by Glasgow School of Art and the University of Glasgow, has developed a creative vacuum-assisted climbing apparatus that enables emergency and service personnel to easily transcend a building facade, and has significant potential in the recreational climbing market.

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Figure 1.3: Re-configurable vacuum forming mould. The 2mm pin system allows for rapid mould making and modification (image source: Brunel University Product Design Engineering student)

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Figure 1.4: Innovative product solution – vacuum-assisted wall climbing device. (image source: Glasgow School of Art final year Product Design Engineering student)

The following student design example (Figure 1.5) from a Swinburne PDE student shows a creative approach to a technical problem, where existing procedures are discarded in favour of an innovation that presents a cost effective and sustainable solution that minimises the environmental impact of agricultural production. The problem of environmental contamination resulting from airborne spraying of crops was examined and addressed through a design that applies the fertilisers and pesticides directly to the plant using a transdermal delivery tape application system.

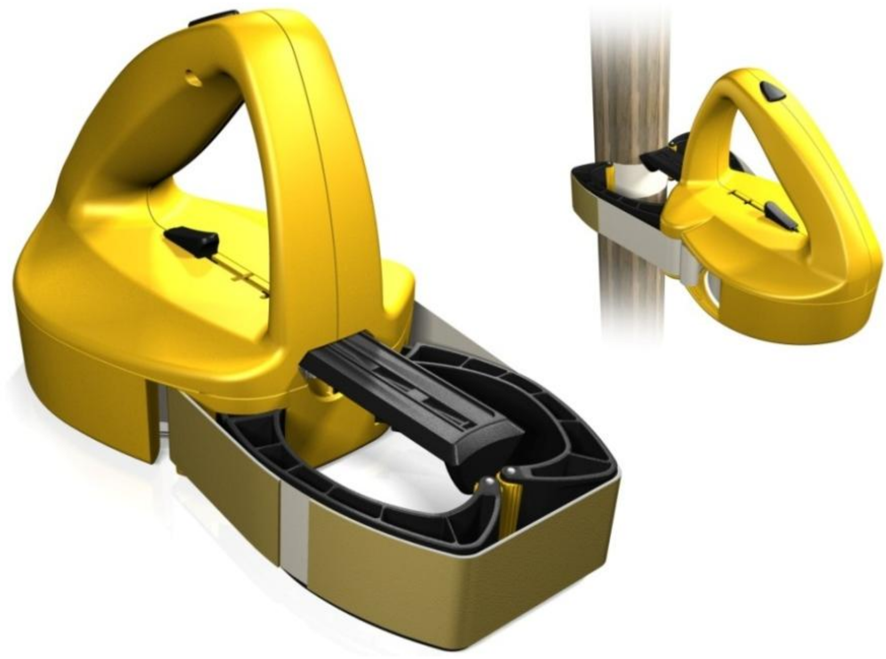

Figure 1.5: Innovative product solution - device to apply chemically-impregnated tape to grapevines to eradicate the environmental contamination that results from airborne spraying and soil leaching (image source: student design – Swinburne final year Product Design Engineering student)

1.7.4 The importance of sketching

"Sketching is one of the most important activities in the design and development of new products" (Rodgers et al. 2000). The need for visual 'artistic' skills in engineering as part of designerly capability has also been acknowledged in various ways (Stewart 1999). Sketching is an activity that is not only integral to the design process, but is closely related to developing creativity. It facilitates the contextual citing of the design intent enabling "designers to handle different levels of abstraction simultaneously" (Cross 2000, p. 22) and provokes creativity through analogical reasoning and reinterpretation of the sketch (Goel 1995).

Sketching enables the abstract development of a solution to an 'ill-defined problem' through the visualisation of mental imagery (see Figure 1.6). This articulation of the concept facilitates a discussion not only with the designer's peers and clients, but more importantly with oneself as a recording and reflection process. In the context of engineering practice, sketching serves multiple social and cognitive functions, which may be hampered by the introduction of CAD (Henderson 1991). It is imperative that engineering graduates are fluent at creative exploration and critical reflection, and are effective communicators of design intent.

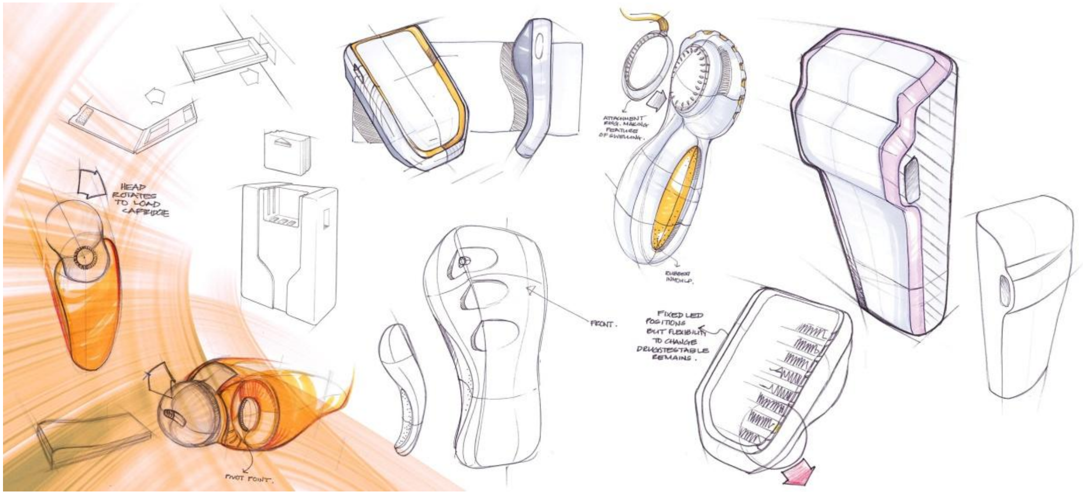

Figure 1.6: Aptitude in sketching facilitates ideation, styling, and functional design.
(Image source: final year Swinburne Product Design Engineering student)

Despite significant research that links sketching and creativity, it is unusual for engineering curricula to develop the freehand sketching skills essential for design conceptualisation and communication, thus limiting the ability of engineering graduates to explore design possibilities. Sketching enables abstract idea development and is not just a documentation and communication process; rather it facilitates the creative process through contextual citing of the design intent.

Sketching is fluent, flexible and inaccurate and because sketches are ‘rough’ there is less reluctance to discard them in favour of alternative designs. Sketches are fast, implicit, inexact and abstract, require minimal commitment and serve both analysis and simulation requirements (Lipson et al. 2000). Goldschmidt in her definition of sketching dialectics, refers to a dialogue between reflective criticism (‘seeing that’) and analogical reasoning and reinterpretation of the sketch (‘seeing as’) (Goldschmidt 1991).

Most importantly, sketches allow the designer and engineer the opportunity to explore as many concepts as possible in an efficient and effective manner, before moving into the detailed design stage. That sketching is integral to the creativity process, is reinforced by studies of industrial design students which compared skilled and unskilled sketchers (Verstijnen et al. 1998) who found that those with sketching ability were advantaged by externalisation of mental imagery.

The following example (in Figure 1.7), demonstrates the use of sketching for detail resolution of technical functionality and product assembly. This process is fast and efficient and allows a higher level of technical design exploration.

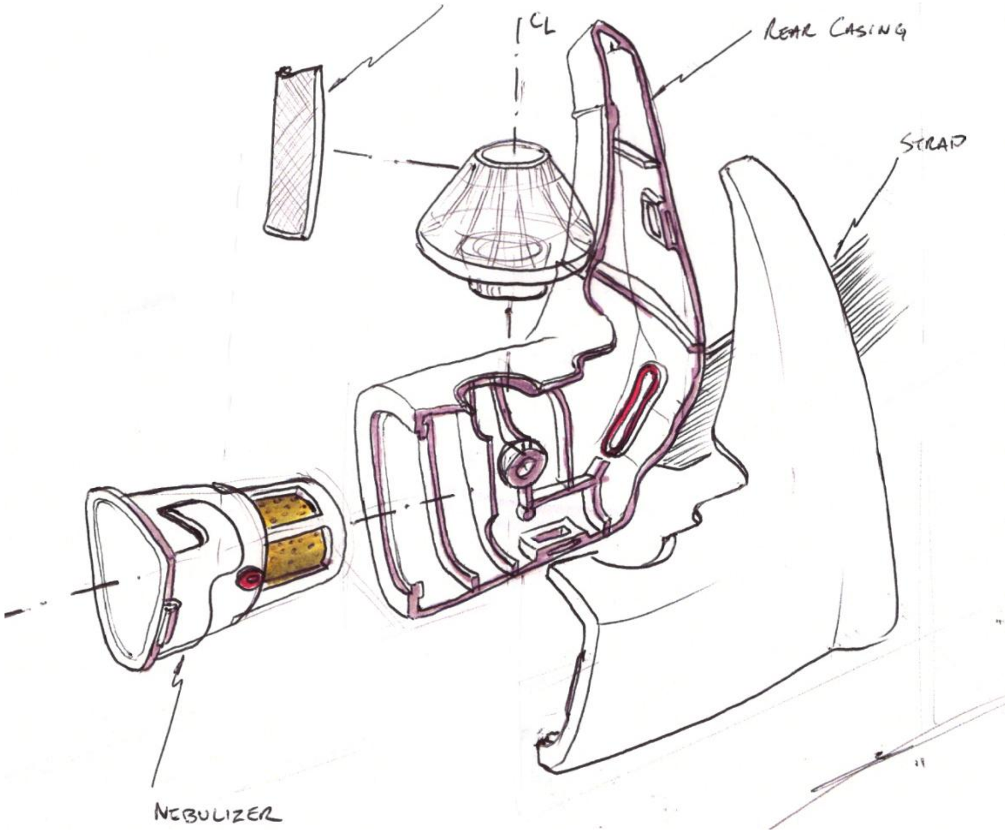

Figure 1.7: Quick sketch to resolve technical layout/product assembly
(image source: Swinburne final year Product Design Engineering student)

Yet many engineering faculties rely solely on CAD for design, neglecting the possibilities that sketching offer in developing creative solutions. This may be due to engineering's technical role in the embodiment stage of product development; however it ignores the value of sketching to detail and technical resolution. As sketching facilitates a creative shift to new alternatives (Goel 1995) it is imperative that engineering students are competent sketchers, capable of articulating unformed ideas and design intent.

"It appears that the very design process is limited by the ability to use graphics as a cognitive extension. This implies the need for training... not only in the standard drafting skills, but additionally in the ability to represent concepts that are more abstract and best represented as sketches" (Ullman et al. 1990, p. 273)

1.7.5 Socially responsibility design (SRD)

The next generation of engineers has the potential to respond to global societal and environmental concerns with appropriate product and service design, but firstly "engineering programs must demonstrate that their graduates have…an understanding of professional and ethical responsibility . . . [and] the broad education necessary to understand the impact of engineering solutions in a global and societal context." (Accreditation Board for Engineering and Technology 1998, pp. 18-19)

It is imperative that engineering serve the community in a socially responsible, sustainable and culturally sensitive manner. "Because of the intrinsic connection of engineering design with values, the engineer as designer shall not only be answerable for his/her engineering capabilities, but also and always for his/her ethical conceptions and behaviour as a moral person." (Eekels 1994, p. 7) Not only do product design teams need to be aware of the consequences of their professional actions, they must also be cognisant of the opportunities afforded them to lead positive change. "Engineering appears to be at a turning point. It is evolving from an occupation that provides clients with competent technical advice to a profession that serves the community in a socially responsible manner....a new educational approach is needed to meet these changing requirements." (Beder 1999, p. 12)

Designing for our complex societies requires anticipation of future needs and cultural sensitivity, but there exists a greater need, that of those at the base of the pyramid (the other 90%). Product design teams must address the societal needs of developing nations through designs that are indeed life supporting, sustainable and empowering. Urgent action is required in many critical areas including the provision of clean drinking water, sanitation, renewable energy, healthcare and disease prevention.

The engineering profession is evolving from the role of technical service provider, to a profession that leads change through understanding of the human, environmental, societal and cultural challenges and the consequences of professional activity (Beder 1997). This will be achieved through a systematic and thorough curriculum grounding in the principles of socially responsible design (SRD) combined with educational opportunities to apply sound engineering practice to real world problems.

Engineers will need not only awareness, but a curriculum driven ethical philosophy that responds to Engineers Australia mandatory generic attributes including;

- understanding of the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development;
- understanding of the principles of sustainable design and development
- understanding of and commitment to professional and ethical responsibilities

Engineering education is well positioned to make a significant contribution to determining attitudinal change amongst the student cohort and thus developing social conscience and sustainable and ethical practice in its graduates.

The examples below (in Figure 1.8) show the diversity of social responsibility products which may include products and service systems that address disaster relief, design for need, inclusive design for the elderly or disabled, and design against crime. In this instance both Glasgow and Melbourne-based PDE students have developed designs in response to the specific needs of disadvantaged communities.

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Figure 1.8: Examples of socially responsible design – a honey extractor made from readily accessible materials for remote Ugandan communities by Swinburne PDE student (left) and solar lantern for developing nations by Glasgow School of Art PDE student (right) (image source: student designs)

1.7.6 Sustainability

"Sustainability cannot be conducted on the sidelines. It can only be achieved through a paradigm shift which results in sustainability becoming part of everyday life, directing the way in which communities and individuals make decisions that contribute to the development of broad social goals." (Hammer 2007)

The UN has estimated that 80 percent of all product-related environmental impacts are determined during the product design stage. If issues of resource depletion, energy usage, material reuse and recycling, environmental degradation and climate change are to be addressed, environmental and social considerations need to be integrated early into the education of design engineers. The responsibility of educators cannot be just to the students and their future employers; engineering education must also be answerable to society for the consequences of graduates' professional behaviour. Engineering graduates need not just awareness of the issues, but an embedded ethical philosophy and the tools to effect reform through sustainable design and product engineering.

Victor Papenek famously declared that "there are professions more harmful than industrial design, but few of them." (Papanek 1985, p. 1) In response to the potential impact of new product development, product design teams must lead initiatives to secure a sustainable lifestyle for future generations through well considered and responsible design and engineering practice; the role of engineering education is to provide the knowledge, aptitude and attitude required to lead this paradigm shift.

Sustainable design practice must be entrenched as a design methodology at the core of all professional activity. This attitudinal change will require product design teams to serve not only their immediate stakeholders (e.g. clients and customers), but also the needs of global societies, including those outside their own market.

The United Nations 'Decade of Education in Sustainable Development' (2005-2014) is almost over. This initiative aimed to "encourage changes in behaviour that will create a more sustainable future in terms of environmental integrity, economic viability and a just society for present and future generations" (UNESCO 2005, p. 6)

Energy and material consumption and carbon emissions have to be reduced, environmental degradation must be halted and alternative technologies developed. But most importantly the needs and aspirations of those currently outside the first world consumer societies must be addressed; not only are they the unwilling participants in relentless and unsustainable development, they also lack the basic elements that constitute a safe, healthy and equitable existence.

This agenda requires programs that teach not only awareness, but also the tools to affect behavioural change and to lead reform in design practice and manufacturing. The next generation of product designers must be imbued with the necessary skills in sustainable deign to address the challenges faced by the manufacturing sector. Designers and engineering students must be taught to question established practice and to be sufficiently confident to make strategic calls that may defy established practice in search of a more sustainable product solution. “We may help them to develop the kind of social and moral responsibility that is needed in design” (Papanek 1985, p. 39)

Many of these goals can be addressed through innovative curricula that inform, encourage and require ‘cradle to cradle’ design considerations including sustainable manufacturing processes and material selection, life cycle analysis, design for assembly and disassembly and a holistic approach to product design that questions not only the impact of the product but also the ‘need’ for the product to exist at all (McDonough et al. 2002). As such, engineering and design educators are ideally placed to make a contribution to reducing the impact of products by encouraging sustainable product and service system solutions.

Encouraging students to tackle major global issues such as sustainable energy production generates awareness, highlights critical issues, and allows students to apply new found technical knowledge to real world problems. In the following examples (Figure 1.9), Product Design Engineering students at both Nottingham Trent University, and Swinburne University of Technology, have been challenged by ethical curricula to develop alternative methods of energy production.

In these design project outcomes, the students have taken existing kinetic energy (found in ocean wave motion and water flow through rainwater collection systems) and translated it into usable clean power, albeit through different methods.

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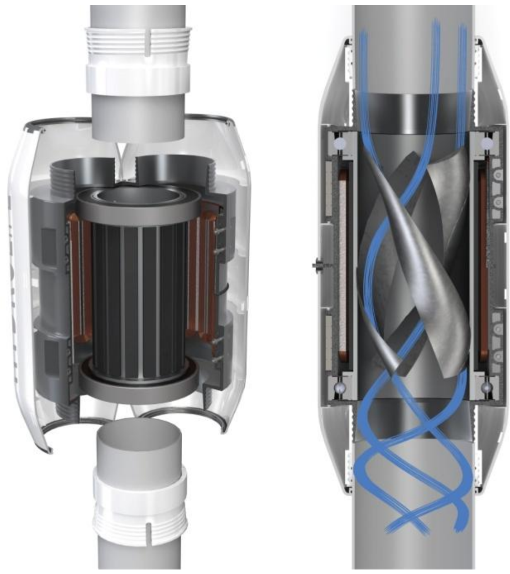

Figure 1.9: Examples of sustainable design for alternate energy production.
left - a wave energy generator by a final year PDE student at Nottingham Trent University and
right - harnessing the kinetic energy of rainwater in building downpipes by Swinburne PDE student

1.7.7 Problem solving: 'wicked' and open-ended problems

In 2008, the US National Academy of Engineering (NAE), working with engineering professional societies, nominated what they believed to be the twenty greatest engineering achievements of the twentieth century.

The main criterion for selection was not technical prowess but how much the achievement had improved quality of life. These achievements which are listed below (in table 1.10) attempt to capture the contribution of engineering to society in making the world a 'healthier, safer, and more productive place.'

1. Electrification	11. Highways
2. Automobile	12. Spacecraft
3. Airplane	13. Internet
4. Water Supply and Distribution	14. Imaging
5. Electronics	15. Household Appliances
7. Agricultural Mechanisation	17.Petroleum and Petrochemical Tech.
8. Computers	18. Laser and Fibre Optics
9. Telephone	19. Nuclear Technologies
10. Air Conditioning and Refrigeration	20. High performance materials

Table 1.10: National Academy of Engineering's list of 20 Greatest Engineering Achievements of the Twentieth Century (data source: NAE 2000)

Concurrently, the NAE panel identified fourteen 'Grand Challenges for Engineering in the 21st Century' as listed below:

- Make solar energy affordable,
- Provide energy from fusion,
- Develop carbon sequestration methods,
- Manage the nitrogen cycle,
- Provide access to clean water,
- Restore and improve urban infrastructure,
- Advance health informatics,
- Engineer better medicines,
- Reverse-engineer the brain,
- Prevent nuclear terror,
- Secure cyberspace,
- Enhance virtual reality,
- Advance personalized learning, and
- Engineer the tools for scientific discovery.

It is evident from this list that the 21st century design engineer will be confronted with ill-defined problems; design problems that will not be solved solely through the appliance of engineering science. These 'wicked' problems (Rittel et al. 1973) will require a new engineering approach, one that incorporates divergent thinking, creative and intuitive processes, and a willingness to embrace unexpected solutions; a designers approach to problem solving.

As discussed earlier, design is a divergent activity, whereas engineering thinking is mostly convergent (Fry 2006). Consequently, it is no surprise that mechanical engineering students can struggle with open-ended problem solving when compared with design students. Engineering curricula tends to utilise constrained problems, where the parameters are set and the outcome is, if not immediately apparent, determined by constraints afforded by material and processes. By contrast designers spend a significant amount of their time dealing with uncertainty, dealing with problem 'framing' in a quest for unique and innovative solutions.

However, many of the 21st century problems facing design engineers will also be poorly defined and their first challenge will be problem definition; this will need experience and confidence when faced with uncertainty. Students need a learning process of construction and confrontation rather than memorisation. Project-based learning allows students to define and analyse the problem, develop alternative strategies to problem solving and to build, enhance and practice their expertise. But not all project-based learning will afford intense exploration and challenge students to work without constraints or parameters, as will an open-ended problem.

Open ended design problems "force students to think creatively and ultimately foster in them an appreciation for developing creative solutions" (Ghosh 1993, p. 116). This requires students to tolerate the unusual, unconventional and unexpected, and to become comfortable with divergent thinking processes. Open-ended problems require problem finding, evaluation, definition and resolution skills together with ideational fluency. It is beneficial to take students away from a problem 'solving' role into a position of exploration and synthesis; enforcing a more holistic reasoning approach with critical analysis and creative expression.

Experience with open-ended or poorly defined design problems (that are not always amenable to the techniques of science and engineering), is invaluable in engineering education. Students must develop flexible and divergent dichotomies, be confident seeking solutions outside their traditional fields of expertise, be comfortable using intuition to solve problems and eliminate the tendency to fixate on prior solutions.

1.7.8 Women in new product development

"If women don't belong in engineering, then engineering as a profession is irrelevant to the needs of our society." (Widnall 2000, p. 15)

Female engagement in engineering careers has traditionally been low in Western countries. It is only since the Second World War that many engineering faculties have admitted women. In Australia, only 9.6% of engineers are women (Engineers Australia 2009) and the enrolment rate of women in engineering degree courses has remained around 14 per cent since the early 1990s (with a high in 2001 of 15.7 per cent). These figures are consistent with global data; in Europe and the USA only 20 percent of engineering students are female, in the UK it is 15 percent.

Yet women are a major consumer group within society, responsible for the selection of a majority of consumer products. New product development companies need stronger female representation in product design teams to bring different perspectives and enable more creative and better targeted product solutions that meet the needs of society and women. By employing more female engineers, companies can better understand their customers' needs, facilitating more appropriate product design solutions, and allowing them to compete more effectively.

However it will be difficult to source female engineers for new product development from the ranks of mechanical engineering. Female enrolments are typically very low in ME, with Swinburne University enrolling only 2 percent female ME students, compared to an overall faculty average of 10 percent (Swinburne RQF Report 2007). However unless engineering welcomes women, it risks becoming marginalized as other fields seek out and make a place for them (Widnall 2000).

It is evident that traditional engineering curricula, such as mechanical engineering, do not appeal to young women as a career choice. This limits the potential for women to contribute to new product development, except in industrial design roles (where female ratios are typically as high as 40 percent). An engineering course with a broader cross-gender appeal would enable women to contribute more significantly to the design and development of new products.

1.8 Future trends in new product development

Industry trends indicate that new product development will increasingly require an interdisciplinary professional capable of operating with distinction in both design and engineering roles. It is already apparent that successful design results from teams that integrate the skills of both engineering and industrial designers through non-combative collaboration built on mutual respect.

The challenges of the next few decades are immense; design teams must lead behavioural change through well considered, appropriate and sustainable products that meet the future needs of all stakeholders, not just their clients and customers.

Confronting climate change inflicted by environmental degradation, reducing the impact of products throughout their life cycles, and enhancing the health, life expectancy and aspirations of those at the base of the pyramid will require real innovation in product design and development. This innovation will not occur naturally, a paradigm shift is required; one that will challenge expected conventions in new product development and impact on design and manufacturing activities.

This new environment will require an interdisciplinary product designer; creative, and adaptable, multilingual in the languages of engineering and design, responsible and culturally sensitive. The new engineering paradigm of Product Design Engineering is a possible solution to the needs identified in this chapter.

1.9 Graduate attributes for roles in new product development

This chapter has identified the need for specific graduate attributes for those employed in new product development (NPD).

These attributes have emerged from the existing literature, industry feedback for those engaged in new product development and from the objectives of engineering regulatory organisations. The research and literature points to twelve key graduate attributes which are essential for engineers engaged in new product development roles. These attributes and critical agendas which have been discussed within this chapter are summarised by the following list:

- mechanical engineering ability
- technical knowledge
- product design skills
- aesthetic styling ability
- sustainable
- socially responsible
- creative and innovative
- user-centred
- wicked problem solving ability
- interdisciplinary skills
- manufacturing knowledge
- industry readiness for roles in NPD

Figure 1.11 (below) identifies the critical educational requirements and engineering practice based agendas that require an educational response, and maps those criteria against the professions currently engaged in NPD; mechanical engineering and industrial design. This comparison, which utilises a similar format to Bates and Pedgley's (1998) comparison between engineering designers and industrial designers, illustrates the critical differences in the graduate attributes of mechanical engineers and industrial designers. It is apparent that neither profession has a full palette of skills that addresses all aspects of new product development. Yet the separation of duties within the product design process can lead to poor internal liaison, development inefficiencies and lack of team and product synergy.

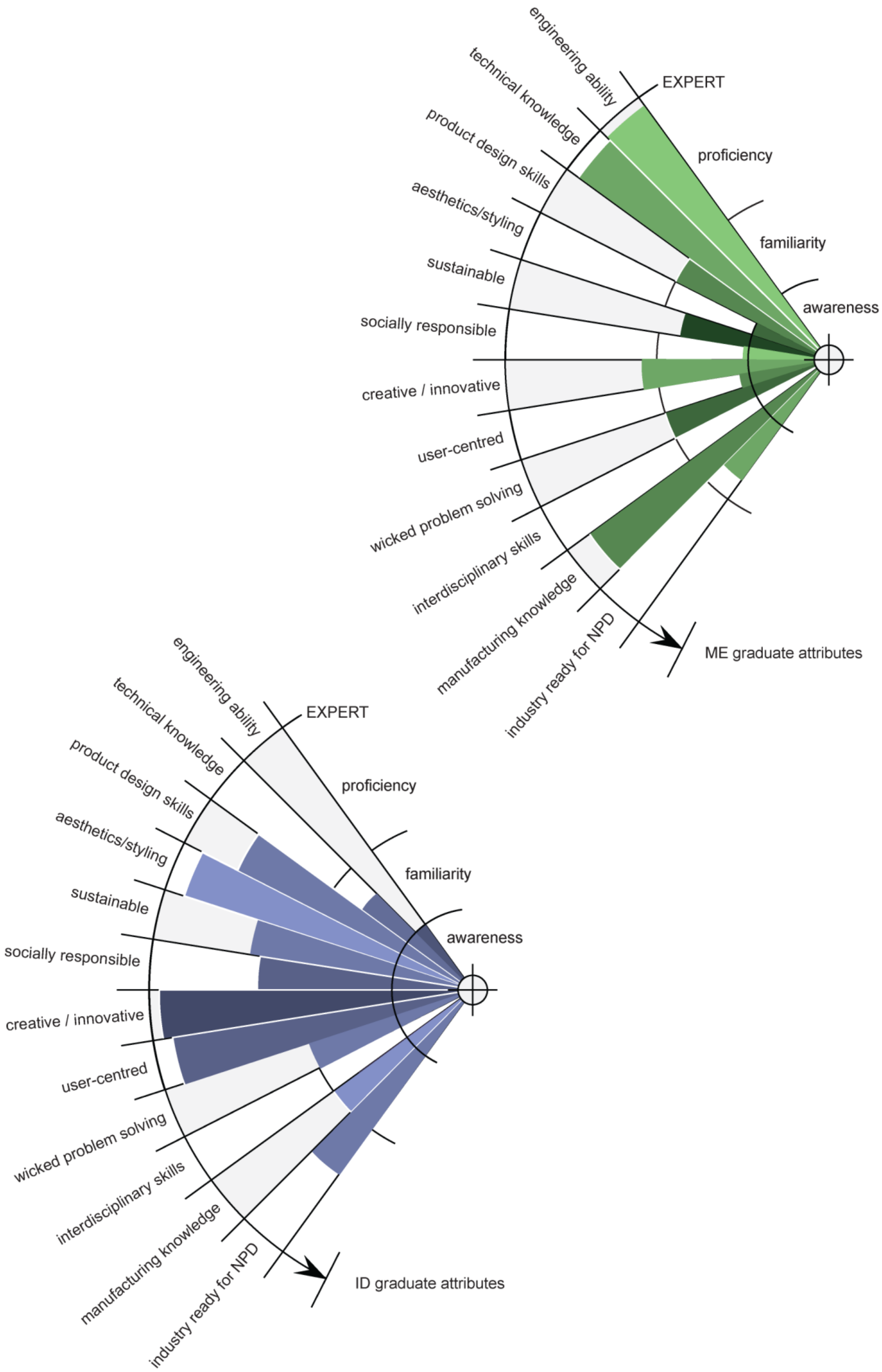

Figure 1.11: A comparative evaluation of graduate attributes and educational issues for new product development against Swinburne mechanical engineering and industrial design curricula (Ian de Vere)

It is evident that a new engineering discipline is required for new product development; one that integrates the skills and attributes of both professions; a creative, user-centred design engineer, with strong problem framing and solving capacity, and proficient in both explorative design and mechanical engineering.

Whilst product design teams need an inter-disciplinary engineer who integrates creative design with technical competency in engineering, it is also likely that a human-centred, design-based engineering program will appeal to women, a demographic which does not normally choose mechanical engineering as a career.

1.10 A comparative study of curricula

Figure 1.12 shows a comparison of typical curricula for mechanical engineering and industrial design. In this instance, the recommended study sequences from Swinburne University of Technology have been evaluated. Whilst all institutions have different programs there is sufficient commonality between undergraduate programs (especially with regard to external accreditation) that the examples used are broadly indicative of global curriculum structures.

It is apparent from perusal of these curricula that the mechanical engineering course whilst strong on engineering science (as per Engineers Australia course accreditation requirements) is predominately theory-based with little opportunity for student experimentation or application of theory into real-world practice through product design projects. There is little evidence of design activity in the early years of the core curriculum, although final year research projects and the specialist studies electives (undertaken in the final three semesters) do offer more design activity. The mechanical engineering curriculum consists of four main components, the largest being foundation and technical studies, whilst the design and management areas of study are significantly smaller. There are only three design subjects, Computer Aided Engineering, Machine Design and Mechanical Systems Design in the four years of the undergraduate curriculum, and none of these offer training in sketching or creative design processes.

	MECHANICAL ENGINEERING	INDUSTRIAL DESIGN
YEAR ONE	HES1300 Robotics and Mechatronics P1	HDC001 20th Century Design
	HES1230 Materials and Processes	HDC002 Methods of Investigation
	HET124 Energy and Motion	HD3D003 Product Design Studio 1
	HMS111 Engineering Mathematics 1	HD3D004 Product Communication
	HES1125 Mechanics of Structures	HD3D007 Product Design Studio 2
	HES1305 Robotics and Mechatronics P2	HDIND121 Ergonomic Interaction Studio
	HET182 Electronics Systems	HDC003 Design Studio
	HMS112 Engineering Mathematics 2	HDC004 Digital Design
YEAR TWO	HMS211 Engineering Mathematics 3A	HD3D008 Product CAD
	HES2330 Thermodynamics 1	HDIND211 Changing Patterns Studio
	HES2340 Fluid Mechanics 1	HD3D001 Exhibition Design Studio
	HES2146M Computer Aided Engineering	elective
	HMS212 Engineering Mathematics 4A	HDIND221 Sustainable Environment Studio
	HES2120 Structural Mechanics	HDIND222 Processes Technology
	HES2310 Machine Dynamics 1	HD3D002 Furniture Design Studio
	HES2281 Materials and Manufacturing1	elective
YEAR THREE	HES3350 Machine Design	HDIND311 Manufacturing Technology
	HES3310 Control Engineering	HDIND312 Sporting Directions Studio
	HES3281 Materials and Manufacturing 2	HDC005 Contemporary Design Issues
	HES3380 Engineering Management 1	elective
	HES4330 Thermodynamics 2	HDIND321 Professional Practice Studio
	HES5320 Solid Mechanics	HDIND322ManufacturingCommunication
	HES4350 Mechanical Systems Design	HDC008 Design Systems and Services
	Specialist Studies Elective unit	elective
YEAR FOUR	HES5102 Research Project	HDG407 Social Patterns Research
	HES5310 Machine Dynamics 2	HDG408 Social Patterns Studio
	Specialist Studies Elective unit	HDG412 Product Interaction
	Specialist Studies Elective unit	HDG413 Digital Technology 1
	HES5380 Engineering Management 2	HDG409 New Technologies Research
	HES5103 Advanced Research Project	HDG410 New Technologies Studio
	HES5340 Fluid Mechanics 2	HDG406 Professional Context
	Specialist Studies Elective unit	HDG423 Digital Technology 2

Figure 1.12: A comparison of curriculum study sequences for Mechanical Engineering and Industrial Design undergraduate courses at Swinburne University of Technology (data source: SUT 2012)

There is little training in the design of plastic parts, which dominate product design. Human related and user-centred issues are also not included in the curriculum. Besides the optional Human Factors subject (which is predominately technical theory) there are no subjects that train engineers to design user-product interaction.

There is also little evidence of the inclusion of critical environmental and societal issues in the mechanical engineering curriculum. This is not to say that these agendas are not discussed (as sustainability is included as a topic within the Engineering Management 1 subject), however there is little evidence that students are challenged to undertake design activity to address these concerns.

It would appear that mechanical engineering graduates, whilst possessing a strong technical basis, have little opportunities to apply their engineering science to product design solutions, especially in the context of critical human, societal and environmental contexts. It is therefore difficult to see how mechanical engineering programs can adequately prepare graduates for roles in new product development.

By contrast the industrial design course offers an educational journey that is almost entirely project based experiential learning with constant design studios throughout the study sequence. Critical agendas including changing demographics, sustainability and social patterns direct the curriculum as does a user-centred philosophy.

As expected by an offering from a design faculty, the industrial design course focuses on developing design skills and creativity, mostly during design activity through open-ended problem solving and scenario-based studio projects.

However the industrial design curricula is very light on technical content with only two technical subjects, Processes Technology and Manufacturing Technology which mainly deal with material properties and manufacturing processes. Despite the type of design products that an industrial designer may be involved in, there is no engineering content such as mechanical systems, linear or rotational mechanics, structural mechanics, electronic systems, material science, risk engineering, or mathematical or critical analysis.

Whilst the industrial designers are imbued with user-centred design skills, and are specifically trained for roles in new product development, their ability to resolve the technical and manufacturing aspects of the product appears to be underdeveloped. This will limit their engagement in the design process to the conceptual 'front end' and they may not be able to contribute significantly to the product resolution.

It is evident that whist there are two disciplines operating in NPD, there is very little overlap of skills and knowledge; both industrial design and mechanical engineering have significantly different training, highlighting the potential for lack of understanding and synergy in product design teams. It is also apparent that neither industrial designers nor mechanical engineers are wholly prepared to contribute in all areas of new product development.

1.11 Limitations to Engineering Design Education

Two decades ago Qarante (1988) observed that the engineer designer concerned with an enlarged systems approach to product design would need to adapt to working in an interdisciplinary and human-centred context of project (not product) management. Since Qarante there have been some responses to the need for 'designerly thinking' (Cross 2006) in engineering design, however in a recent review, Dym *et al*. (2005), suggest that engineering design courses have yet to create an appropriate engineering and design balance.

Product development teams require an integrated and multidisciplinary approach. As noted by Grasso and Martinelli (2007), engineers must be flexible, creative and solution-focussed with a strong understanding of human-centred design and an ability to work in multidisciplinary contexts.

Engineering educators and practitioners are aware of the limitations of traditional teaching methods, which can focus excessively on technical knowledge to the exclusion of other dimensions of engineering design problems (Beder 1999). This limitation is echoed by engineering regulatory bodies worldwide, calling for broader programmes and a greater emphasis on design, creativity and ethical design.

The broad context of mechanical engineering curricula and its closely regulated content does not afford many opportunities for the inclusion of new agendas. Accordingly, training in mechanical engineering does not usually address the new roles or responsibilities of engineers in product design, nor does it necessarily reflect current societal agendas; cultural sensitivity, socially responsibility and sustainable practice. Yet societal expectation requires engineering designers to contribute positively to global societies in a responsible and innovative manner.

It has been noted that engineering curricula continues to address the ‘science’ of engineering, neglecting the contexts into which engineering graduates emerge. (Dym et al. 2005) This is especially problematic for those graduates pursuing a career in product design and development.

1.12 The need for change

Cross (2000) has identified that successful product design in a competitive market can only be accomplished by the integration of skills of industrial design and mechanical engineering.

It is apparent the boundaries between these disparate disciplines are eroding, especially in the product design and development (PDD) arena where designers and design engineers collaborate in new areas of activity to extend the range of service provision. Design consultancies and manufactures require flexible and adaptable engineers who can operate effectively in global multidisciplinary environments. A human centred and creative approach is essential for engineers to contribute to rapidly changing environments and cultural and societal requirements (Akay 2003).

As engineering evolves from technical provision to serving global communities in a socially responsible manner, “it is no longer sufficient, nor even practical, to attempt to cram students full of technical knowledge in the hope that it will enable them to do whatever engineering task is required of them throughout their careers” (Beder 1999, p. 12). Engineering regulatory bodies have recognised the need for a new identity and educational direction for the engineering profession. The ‘Educating Engineers for a Changing Australia’ report (Institution of Engineers Australia 1996) identified the need for “understanding of the social, cultural, global and environmental responsibilities of the professional engineer” (p.22). The SARTOR (Standards and Routes to Registration) accreditation document by the Engineering Council UK requires universities to show how graduates could achieve ‘the ability to be creative and innovative.’ “It is now up to the educational institutions to discover ways of fostering creativity in students” (Baillie et al. 1998, p. 36).

Yet more than a decade later, it is difficult to see much evidence of curricula that respond directly to these requirements, by addressing societal agendas and developing creativity. Engineering course accreditation processes can be barriers to curriculum innovation, revealing an entrenched suspicion within the engineering community of design curricula, and a reluctance to reform the science-based theory model. However, new engineering pedagogies such as Product Design Engineering are indicative of engineering programs that offer an appropriate interdisciplinary response, unencumbered by traditional expectations.

1.13 The emergence of a new engineering discipline within NPD

Industry trends indicate that the roles and responsibilities of the engineering designer in product design and development have changed from technical resolution to a more central role in the planning and design process. Design engineers are often engaged in creative ‘front end’ design activities (typically the domain of industrial designers) in addition to systems engineering and manufacturing resolution roles.

“Current trends in technology and our increasingly complex society and workplace require engineers to have a wider variety of skills and a broader understanding of engineering as a discipline if they are to be successful.” (Pappas 2002, p. 1) However, it appears that engineering curricula have been based largely on an ‘engineering science’ model (Dym et al. 2005) at the expense of the development of design and creativity. This has resulted in graduates who are less than ideal for product design environments, where engineers are required to possess a different skill set; design acumen, creativity and a human-centred focus.

Conversely, whilst industrial design has focussed on design creativity and the needs of user and society, its graduates have been criticised for lacking the technical depth, professional rigour and analytical enquiry of the engineer.

However recent curriculum developments have seen the emergence of new engineering pedagogy that support integrated product design. These new educational models (which include Product Design Engineering) show evidence of an attitudinal shift that leans “toward a more explicit recognition of design as a distinguishing feature of engineering practice and a motivating factor in the learning of engineering.” .(Dym 1999, p. 146)

These programs, through the integration of user-centred design curricula, develop interdisciplinary engineers who blend the intuitive creativity of industrial design and sound engineering practice and technical knowledge, with a strong understanding of social context, user and environment. Product Design Engineering is one example of new engineering curricula that develops specific graduate attributes for integrated product design. Whilst a relatively new engineering discipline, Product Design Engineering is gaining support with global growth and distribution of curricula.

This interdisciplinary engineering discipline addresses the key concerns of engineering academics and regulatory organisations; “The purpose of engineering education is to graduate engineers who can design” (Dym et al. 2005, p. 103) and “as educators, we are responsible for stimulating creative thinking among our students... our ultimate goal is to require original creative work as part of every engineering course.” (Richards 1998, p. 1038) Graduates are expected to be capable of operating within both professions as fully accredited engineers whose methods are enhanced by design processes; creative and responsible product designers, rather than technical practitioners. “New paradigms such as Product Design Engineering are catalysts for significant change and directly respond to industry needs and societal demands” (de Vere et al. 2010, p. 117).

1.14 Developing a new engineering pedagogy

Product Design Engineering emerged as a new engineering discipline in Scotland in the late 1980s, responding to changing manufacturing environments that demanded fluency in both engineering and design. Originating from collaboration between the Department of Mechanical Engineering at the University of Glasgow and The School of Design at Glasgow School of Art, it was soon followed by similar pedagogy at the University of Strathclyde, and other institutions.

This new engineering curriculum integrated the design and engineering disciplines to create one model of reflective practicum with "design a continuous thread running through the teaching" (Green et al. 2001, p. 4), an attribute favoured by the Grant Report, The Formation of Mechanical Engineers: Present and Future Needs (IME 1985). The PDE program proposed to alleviate the educational and professional void between design and engineering and to introduce many of the educational topics raised by Donald Schön in 'Educating the Reflective Practitioner' including reflection-in-action and joint experimentation on open-ended problems.

The Glasgow School of Art / University of Glasgow PDE program collaboration is now in its sixteenth year of operation and has been described by Andrew Summers, former Chief Executive of the Design Council as "a world-class best-practice exemplar," and credited by the Institution of Mechanical Engineers with "bringing back the joy and creativity to engineering."

In 1997, Swinburne University of Technology established its own PDE curriculum with inter-faculty collaboration between the School of Design and School of Mechanical and Manufacturing Engineering (now the Faculty of Design and Faculty of Engineering and Industrial Sciences). This interdisciplinary course, which will graduate its twelfth student cohort in 2013, has firmly established itself in the Melbourne employment sector with 100% graduate employment statistics and career pathways into the product design, automotive, and manufacturing industries.

In 2008 the Swinburne Product Design Engineering course was commended by Engineers Australia during course reaccreditation for its “innovative” curricula. This may be due to the curricula meeting the aims of the regulatory body in “Engineering Design: A National Asset” which asserts that “synergistic attitudes and relationships must be developed and fostered between engineering designers and industrial designers, who are natural professional companions” (Engineers Australia 2008, p. 4)

The success of this new discipline is evidenced both by the enthusiastic reception by industry and the propagation of similar courses worldwide. There are now at least twenty-eight accredited engineering courses that have integrated industrial design teaching into engineering curricula, albeit in differing models. Whilst PDE is mostly concentrated in the manufacturing regions of the UK (where it originated), the geographic spread of PDE style curricula includes Western Europe, North America, South America, India and Israel (as shown in Figure 1.13).

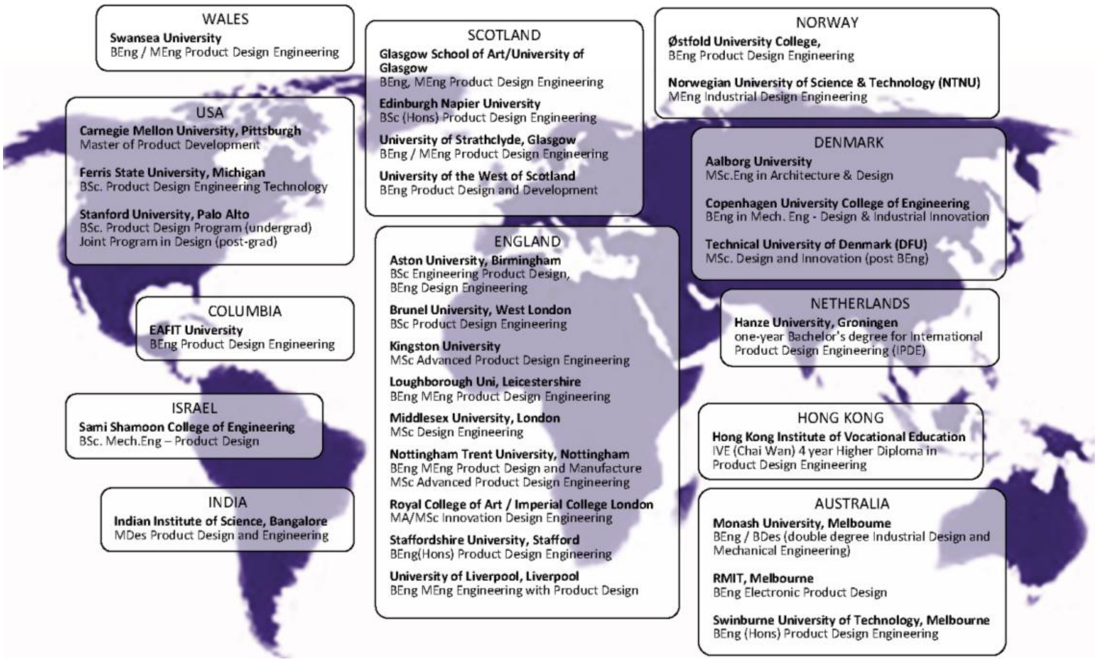

Figure 1.13: Global distribution of Product Design Engineering courses (image: Ian de Vere)

1.15 Describing Product Design Engineering

Product Design Engineering (PDE) consists of an integration of two traditionally disparate fields – (mechanical) engineering and industrial design – and its intention is to develop an interdisciplinary professional is ideally placed to lead product design and development teams and guide reform towards more sustainable and responsible product manufacture. This new discipline, which evolved in response to the needs of a changing manufacturing industry, resulted in a new style of engineering practitioner; one with fluency in both engineering and design. The first PDE course aimed to integrate the two disciplines with a view to emphasising critical reflection on the product design process (Green et al. 2001).

It is important to distinguish the Product Design Engineering curricula from the Industrial Design Engineering (IDE) courses in the UK and Europe. Whilst these courses similarly integrate design and engineering with the intent of multidisciplinary curricula, in the IDE model the engineering content is integrated into an industrial design program (whereas the PDE model integrates design into mechanical engineering), and IDE graduates are not always recognised as engineers.

The PDE model, whilst not neglecting the 'science' of engineering, aims to develop graduates who are prepared for the 'practice of engineering'. It is intended that graduates will meet the requirements outlined by Grasso and Martinelli (2007) for a new breed of engineer who is "not only a truly comprehensive problem solver, but a problem definer, leading multidisciplinary teams of professionals in setting agendas and fostering innovation" (p. 38).

The professional competency of multi-disciplinary graduates attracts scrutiny, with some critics defining them as generalists, however the intent of the PDE model is to develop 'integralists' (Eekels 1987) who are fluent in all areas of new product development. Students are taught through problem-based learning (Denayer et al. 2003) and develop sensitivity for the language of design as well as mathematics (Dym 1998). They also have a greater appreciation for the aesthetic qualities of materials selection in the product design process (Ashby et al. 2005).

Examination of the PDE course descriptors from a selection of institutions show a commonality of programme intent which align with both the needs of the new product development industry and the objectives of engineering accreditation organisations identified earlier in this chapter, as follows:

- creativity and innovation combined with technical strength;
- interdisciplinary education;
- user focused/humanistic;
- social responsibility/focus on societal benefits;
- sustainability and
- an emphasis on design

This similarity in purpose is reflected in curriculum mission statements for Product Design Engineering courses, such as those sampled below:

> "The Product Design Engineering programme creates design engineers whose strength lies in their capacity for creative synthesis and the development and design management of engineering and consumer products." [University of Glasgow 2012]

> "Product Design Engineering integrates engineering and industrial design to develop creative, human-centred design engineers. Innovative, sustainable and socially responsible solutions are sought for real world problems, through interdisciplinary interaction and close collaboration with industry partners." [Swinburne University of Technology, 2009]

> "Product Design Engineers have the challenging task of combining creative, aesthetic and technical design skills, with a background of engineering science. It is important that they are able to design a new product that satisfies the original functional specification and is appealing to the potential market. Our IMechE and IET accredited programme in Product Design Engineering has been developed to provide industry with graduates possessing a wide range of professional engineering knowledge and design skills. The programme provides a thorough understanding of design principles, manufacturing processes, and

manufacturing technologies. This is supported with a background in mathematics, statistics and the principles of engineering science.”

[Loughborough University 2013]

“The Product Design major concerns itself with the conception and design of products, services and experiences for the benefit of society. The programme teaches a design process that encourages creativity, craftsmanship and personal expression and emphasises brainstorming and need finding to discover latent or un-served human need."

[Stanford University, USA - retrieved from website 2009]

“This profession (PDE) is consolidated from the research and the analysis of man’s needs, the generation of innovating ideas, the creative design of products as solutions for said problems, and all of this, with the contribution of the engineering sciences, the selection of manufacturing materials and processes for the effective management of business projects.” [Universidad EAFIT, Columbia - retrieved from website 2009]

“The study combines humanistic, esthetical (aesthetical) and technological sciences with practical skills in creating functional, user-satisfying products.” [Østfold University College, Norway 2009]

“This course bridges the worlds of design and engineering, producing true hybrid professionals who will move immediately into companies as design engineers and product development specialists. This rare degree format has proved to be highly regarded by industries worldwide for producing valuable employees.” (Brunel University 2009)]

It is apparent from these statements that regardless of the institution, there is commonality of the program intent; to develop an industry-ready professional skilled in both engineering and design, to contribute to product design and development - a new engineering pedagogy for product development specialists.

1.16 Curriculum commonality of intent

A detailed investigation and curriculum benchmarking survey (see chapter 2) across the global examples of Product Design Engineering curricula, has revealed that the key graduate attributes as mandated by global engineering regulatory organisations and required for roles in new product development, are apparent in all iterations of PDE curricula.

Product Design Engineering programs not only have a commonality of intent with regard to the integration of industrial design content into a mechanical engineering curriculum, but maintain a curriculum consistency with regard to key issues such as sustainability, socially responsible design, creativity, design skills (including sketching), user-centred design and problem solving ability.

Curricula appear to be similar in the ambition to integrate the design and engineering disciplines to produce a more rounded 'interdisciplinary' graduate with a balance of technical and manufacturing knowledge, and aesthetics and creativity and human-centred sensibilities.

1.17 Graduate attributes of product design engineers

This chapter has identified essential graduate attributes for roles in new product development. Earlier, in section 1.10, the attributes of mechanical engineers and industrial designers were evaluated against those criteria revealing that neither discipline possess the full portfolio of the skills required in new product development. This does not mean that they are unsuitable for employment in that environment; rather that their skills are limited to their area of specialisation and that cross-discipline consideration may not always be evident.

In Figure 1.14 (below) the graduate attributes of Product Design Engineers are mapped against the same criteria, revealing a strong correlation between NPD industry needs and PDE curricula.

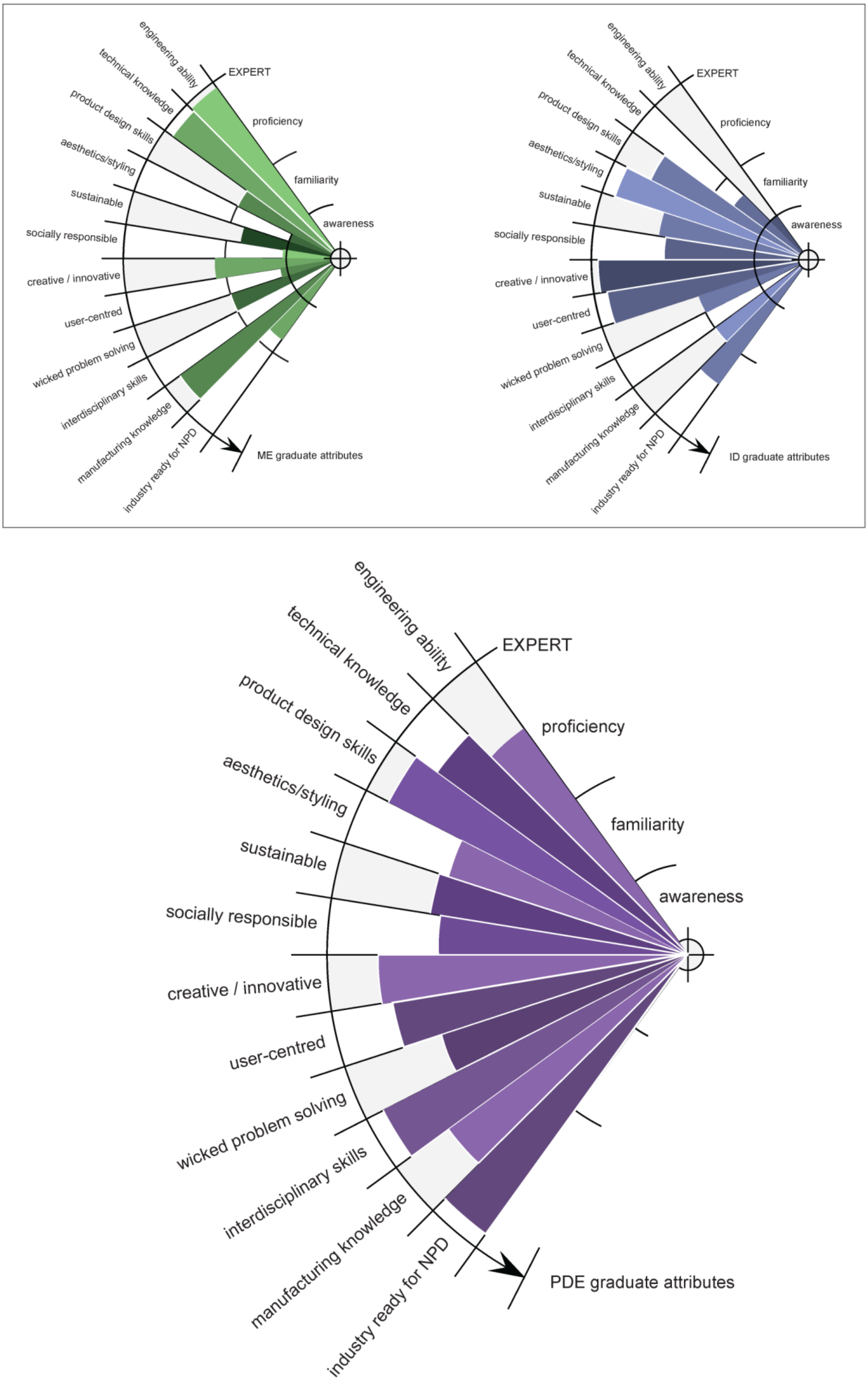

Figure 1.14: A comparative evaluation of graduate attributes for Product Design Engineering (in purple, compared to mechanical engineering (green) and industrial design curricula (blue)

It is evident that the Product Design Engineering curriculum addresses key criteria and agendas identified by:

- engineering regulatory and course accreditation organisations,
- luminary engineering academics and
- the new product development industry.

As such, it appears to represent a solution to issues within new product development by balancing the parallel demands of engineering and design practice, without significant loss in capability in either profession.

1.18 Conclusion

This chapter has dealt with the challenges facing product design and development teams in the near and immediate future. The product design industry must respond to existing and emerging challenges with a new paradigm for practice that responds to global societal and environmental needs, empowers individuals and communities, respects cultures and embraces the emerging technologies that will impact on established protocols and the definition of professional disciplines.

The role of engineers in the product design and development process is shifting and will continue to be redefined as technological, environmental and societal considerations impact on professional practice. It is felt that these challenges are best addressed with a complex and multi-skilled practitioner, who bridges traditionally rival professions and facilitates a new era of collaboration, understanding and respect. (Grasso et al. 2007).

The product design and development process can be enhanced by innovative engineers, but often is hampered by inflexibility, poor understanding of user needs and cultural insensitivity. New product development will profit from a more targeted approach to engineering education that seeks to impart appropriate skills for new product development that result in responsible practice and creative outcomes. And both society and environment will benefit from an engineer who is creative, innovative, adaptable and responsible; who can contribute to appropriate product design through new professional synergies and perspectives.

The product design and development industry is expected to address the future needs of our societies and environments. This will require new skills, enhanced communications and new synergies between stakeholders. The next generation of engineers, properly prepared, can direct the product design and development process confidently in new strategic directions.

The role of engineering education in appropriate new product development cannot be underestimated. Educators have a responsibility to global communities to produce engineering graduates with embedded ethical and creative philosophies who are well prepared to make a significant contribution to environmental and societal issues.

This chapter has identified critical graduate attributes and established the 'need' for new multidisciplinary engineering educational models to contribute to new product development. The Product Design Engineering integrated curriculum has proven successful (across numerous global examples) in developing creative and technically competent engineering designers with a human-centred and responsible approach.

This relatively new engineering discipline appears well positioned to make a contribution to new product development by balancing the critical considerations of both disciplines. It is a seemingly appropriate response to both the need identified by many (including Cross, Qarante and Grasso and Martinelli), for interdisciplinary engineers who are creative, flexible and human-centred, and the call by engineering regulatory bodies (Engineers Australia, SARTOR, etc) for curriculum development in the areas of creativity and social responsibility. As such, this new engineering paradigm responds to critical industry and societal demands and appears to be a viable alternative to the more established NPD professions of industrial design and mechanical engineering.

Chapter Two will investigate global product design curricula to evaluate this global trend in engineering pedagogy and new engineering discipline, against the criteria (revealed in this chapter) set by engineering regulatory organisations and new product development industries.

Chapter two: Examination of global PDE curricula

2.1 Overview

Chapter One identified the ‘need’ for a new type of engineer; one with creative design skills and a user-centred approach who is specially trained for roles in new product development. Key graduate attributes were identified and initial research suggests that the PDE curriculum is an appropriate educational response to develop the specific skills and attributes required for NPD industries.

Product Design Engineering was proposed as a possible solution as it appears to address the key objectives and requirements of product design teams, and to address the concerns of engineering regulatory organisations with regard to creativity, design and social and environmental considerations. Thirty similar global programs were identified that appear to offer accredited multidisciplinary engineering programs that integrate industrial design and mechanical engineering curricula.

This chapter examines in detail the global trend in Product Design Engineering curricula through a detailed survey of international PDE programs. It identifies areas of curricula commonality, finds evidence of universal pedagogical intent and measures and documents program delivery and outcomes against a range of critical criteria, including graduate attributes identified as important to new product development.

The results of an extensive international curriculum benchmarking survey are evaluated, which examined multiple aspects including:

- the growth and diversity of PDE curricula,
- student demographics and retention,
- multidisciplinary ratios (design/engineering),
- curriculum (design skills, creativity, user-centred design, critical agendas),
- graduate attributes,
- industry engagement,

- course recognition in industry and community,
- employment rates and graduate pathways, and
- comparisons between PDE and industrial design and mechanical engineering

This chapter examines those international Product Design Engineering programs in detail, through a curriculum benchmarking survey, to determine whether Product Design Engineering is:

- a global trend in new engineering pedagogy,
- addresses requirements of engineering regulatory organisations, and
- an appropriate solution for the needs of new product development.

Chapter Two concludes with Case Study 1, *Examination of the Swinburne PDE Curricula,* which examines a specific Product Design Engineering curriculum; highlighting the content, delivery and relevance of the curriculum, graduate career pathways, and multidisciplinary educational concerns.

2.2 Introduction

Product Design Engineering has been identified as a new model for engineering education, and appears to be a growing global trend. Its approach to engineering education attempts to address both industry and societal needs and develop creative and responsible methodology through a focus on integrated design skills and key agendas. In doing so, it appears to address the needs of the new product development industry for user-centred and creative engineers.

Similar curricula (i.e. engineering courses with significant design content) have been identified in twenty-eight universities across twelve countries. Not all of these courses are branded as Product Design Engineering, however there appears to be significant similarities in curriculum intent to warrant further examination. The curriculum benchmarking survey identified that whilst there may be program variations, there is evidence of a global trend towards multidisciplinary design-engineering education.

Key graduate attributes have been identified earlier in this research (in Chapter One) for new product development engineers, including engineering proficiency, technical knowledge, product design acumen (inc. sketching, aesthetics and styling ability), sustainability and social responsibility, creativity and innovation, a user-centred approach, 'wicked' problem solving ability, interdisciplinary skills integration, manufacturing knowledge and readiness for practice in NPD. In addition, key issues for education have been identified including female participation, cross-discipline skills integration, and project-based learning through design projects.

This chapter, through its examination of multidisciplinary design-engineering curricula, seeks to discover whether PDE programs respond to the expectations of engineering accreditation organisations and develop engineers with the appropriate graduate attributes for employment in new product development. It aims to understand the Product Design Engineering paradigm and compare it with other NPD professions, specifically mechanical engineering and industrial design.

2.3 Rationale

New product development is a convergence point for engineering and design practice. Previously graduates have been prepared for roles in product design through either engineering education (mechanical engineering) or within design schools (industrial design), but recognition of the need for greater synergies between industrial design and engineering training has led to the growth of a new engineering paradigm; Product Design Engineering.

Since the emergence of Product Design Engineering, in Glasgow in 1987, many comparable courses have emerged with apparently similar intent; to develop an interdisciplinary professional with aptitude in both engineering and design. These programs appear to respond to calls from leading engineering academics and engineering regulatory bodies (e.g. SARTOR, Engineers Australia, ABET) for flexible, creative and human-centred engineers with multidisciplinary sensibilities.

This research examines the new engineering discipline through examination and benchmarking of global PDE curricula, in particular, programs that purport to develop, human-centred creative engineers for roles in new product development.

An international survey was conducted to compare and evaluate these courses, to attempt to understand variations in curricula, establish common areas of focus or concern, and to define characteristics of this model of multidisciplinary engineering education. Of particular interest in this analysis was the integration of engineering and design, the fostering of creativity and human-centred design, the inclusion of critical issues such as sustainability and socially responsible design, female participation, industry relevance and resultant graduate pathways.

The survey, which I believe is the first to examine PDE curricula on a global level, aimed to define Product Design Engineering as a distinct engineering discipline; one that responds directly to the needs of new product development.

2.4 The data collection process

This research was conducted in accordance with the requirements of the Swinburne University Human Research Ethics committee, who granted approval for a 'Survey of Product Design Engineering Curriculum and Pedagogy' on 19 August 2009. (Ethics Clearance No. SUHREC 2009/168)

The 2010 PDE Curriculum Survey was developed using the Opinio on-line survey software (hosted by Swinburne ITS) that allows surveys to be produced, published and completed through a regular web browser. This software enabled a survey comprising qualitative, quantitative, multiple choice and direct response questions which was issued (via email invitation) to globally distributed academics.

Twenty-eight courses were identified as suitable for inclusion in the survey as they represented examples of engineering programs with significant product design content. As the instances of Product Design Engineering curricula are relatively small, the sample group was expanded by inclusion of programs with similar intent, to provide broader and more reliable data, and to provide opportunity for comparison with differing approaches to multidisciplinary design/engineering education.

The survey was specifically targeted at program coordinators or those academics responsible for curriculum development with regard to the identified Product Design Engineering (or similar) programs.

Whilst more than half of the selected programs are titled as Product Design Engineering, additional courses have been included in this survey as they represent a variation of approach to multi-disciplinary design-engineering education, such as double degrees, design majors and Masters specialisation courses.

Targeting specific individuals with responsibility for curricula (rather than all instructors engaged in these programs) was a deliberate exercise in purposive sampling, which limited the survey size but ensured accuracy and consistency of data gathering. It should be noted that the resultant sample size does not allow for statistical generalisations, but this was never the intention. What has been achieved through this survey is a representative targeted convenience sample.

The curriculum benchmarking survey (which is detailed in Appendix 1) focused on examination of programs that represent new directions in engineering education, in that they integrate design and engineering curricula with the aim to develop creative, human-centred engineering graduates for roles in product design. The survey which contained thirty-five questions, aimed to provide evidence and data to support the identification of the global trend of these new design-led engineering curricula.

2.5 Global response to survey

Seventeen academics responded and completed the curriculum survey. The response rate of seventeen academics representing fifteen institutions was significantly higher than expected, and represented a wide diversity of curricula across all seven global regions engaging in this type of engineering education. The number of respondents (N=17) whilst a small sample group, was statistically high and represented greater that 50% of global course representation (only 28 courses were identified as PDE or similar). Responses were well distributed with responses from all regions, as follows:

- Australia (2)
- United Kingdom (4)
- Europe (4)
- South America (1)
- United States of America (2)
- Middle East (1)
- Asia (1)

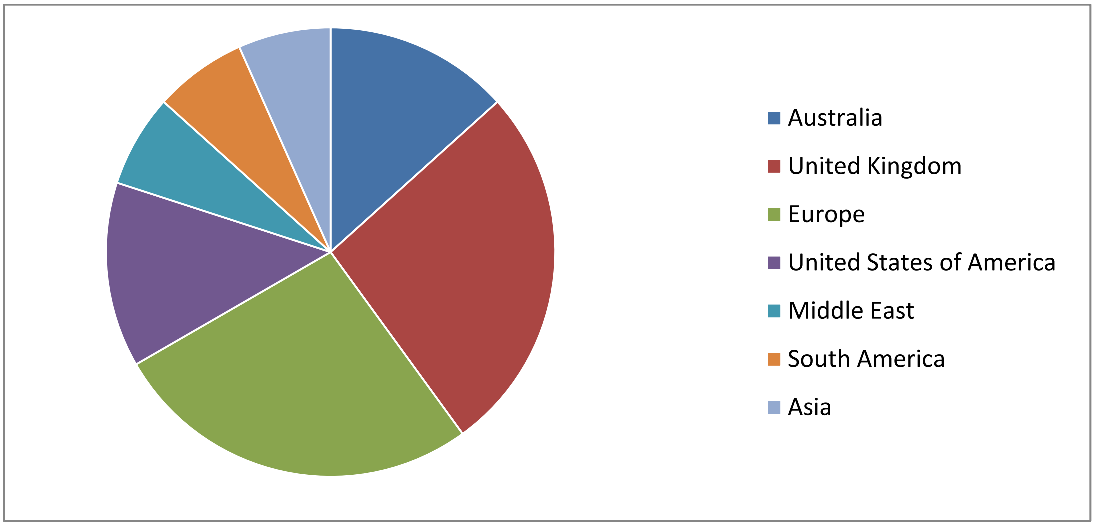

Figure 2.1: Global distribution of responses to the 2010 PDE Curriculum benchmarking survey (data source: PDE Curriculum Benchmarking Survey 2010)

A survey sample's ability to represent the wider opinion has to do with the sampling frame; that is the list from which the sample is selected. As all course leaders were invited to respond (ensuring the survey was free from selection bias) and responses were well distributed across global product design engineering curricula, it is felt that the results are representative of the discipline.

2.6 Degree outcome diversity

Additionally, the survey responses represented the diverse range of Product Design Engineering degree variants including:

- eight fully integrated multidisciplinary PDE courses (BEng, MEng),
- one double degree (BDes/BEng),
- 3 T-shaped curricula- one year/final year course (after 3 years of Mech. Eng),
- several Masters level courses (MSc, MA, MEng and M.Product Design),
- a one year international degree course (BEng), and
- a higher diploma

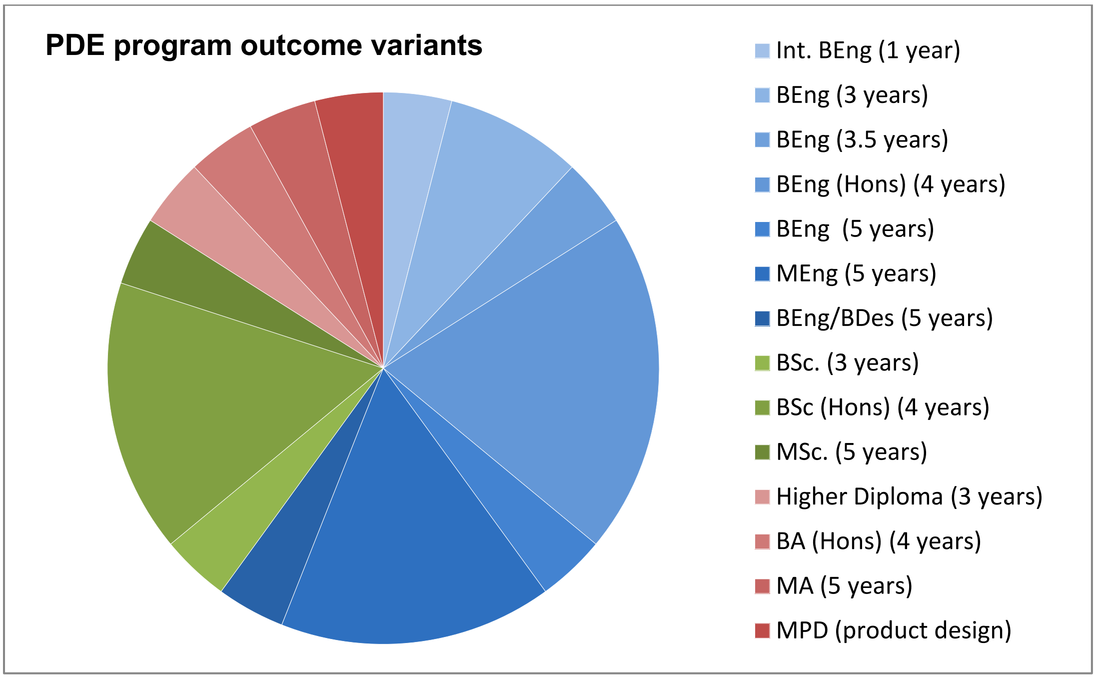

Figure 2.2: Global program outcome variants of PDE-style curricula
(data source: PDE Curriculum Benchmarking Survey 2010)

However as evidenced in Figure 2.2, the majority (60 percent) of surveyed courses culminate in an Engineering qualification (as shown in blue tones), significantly more than the other outcomes which included Science degrees (24% shown in green) and other variants (16% shown in red).

The 'engineering' qualification is important, as it is the degree outcome that distinguishes Product Design Engineering from other multi-disciplinary design-engineering programs. The majority of PDE courses are 'engineering' curricula with BEng/MEng degree awards, although there are some more design focussed courses (similar to Industrial Design Engineering) that confer Science or Arts qualifications.

The decision to include such a wide variant group in this curriculum benchmarking research had two purposes. Firstly, from an explorative point of view it ensured that different paradigms (e.g. the T-shaped courses from the USA) could be compared and evaluated, and secondly it allowed the research to be sufficiently broad in focus to more accurately identify global trends and directions in engineering education.

In this analysis, both raw data and interpreted data will be presented and discussed. In some instances, the data from outside the true PDE courses has been excluded to more exactly clarify the paradigm that is Product Design Engineering. As the survey responders were promised anonymity, the names of the specific programs and institutions have been omitted and all efforts have been made to ensure that individuals and their programs cannot be identified (with the obvious exception of the Swinburne PDE program previously examined in detail within this research).

2.7 Global growth of PDE curricula

Whilst not all institutions responded to the survey, it was possible using information from the survey respondents to develop an indication of the global growth of Product Design Engineering curricula (see Figure 2.3). Whilst this graph does not include data from all institutions offering PDE curricula, it is indicative of the progressive uptake of these new engineering curricula during the last twenty years since the first course was offered in Glasgow. What is evident is a steady growth in program numbers and global distribution of this pedagogy.

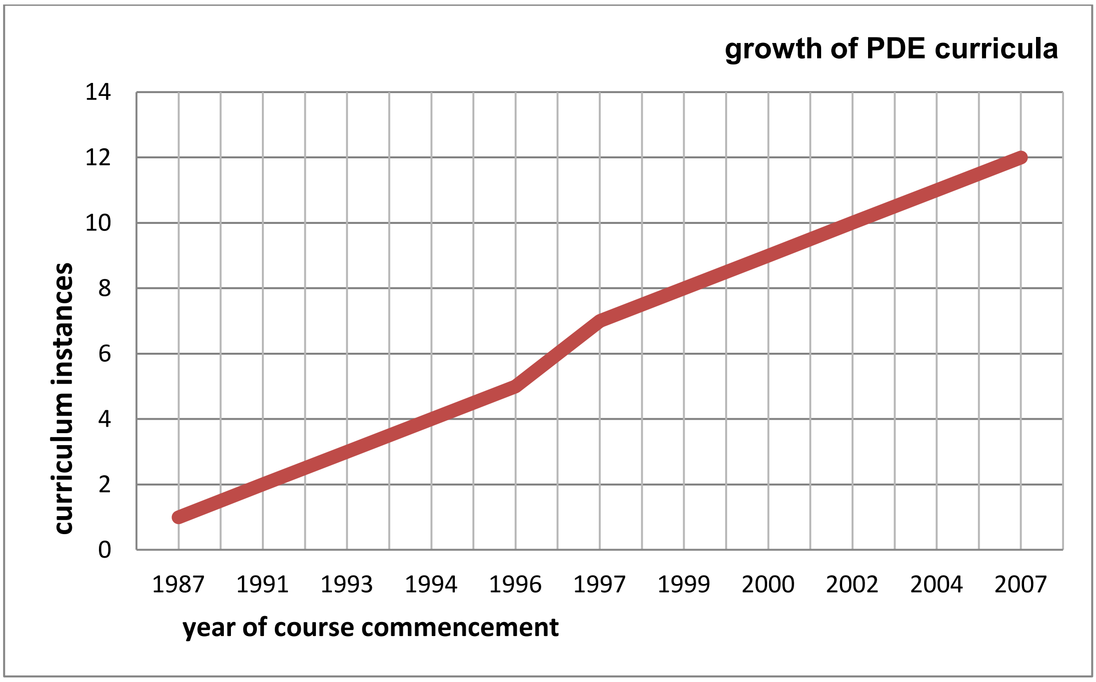

Figure 2.3: Global growth of PDE curricula – start dates of surveyed programs (data source: PDE Curriculum Benchmarking Survey 2010)

2.8 Student demographic

As identified in Chapter One (Section 1.7.8), female engagement in engineering has traditionally been low. This has been reported as a result of social marginalisation and problems associated with the curriculum. "It is likely that a number of curriculum changes will be necessary if the number of women entering university is to be increased significantly. Women students tend to prefer a broader curriculum than men and one which includes some social science and humanities, and a problem oriented curriculum." (John 1995, pp.100-101)

Product Design Engineering however, has proved appealing to a wider demographic, distinct from the typical engineering student cohort. Female ratios are unusually high across all PDE programs when compared to mechanical engineering courses; although the curriculum typically has 50 to 60% mechanical engineering content. It appears that integration of design (with its human-centred approach) into traditional engineering curricula is attractive to young women who otherwise might not have chosen an engineering vocation.

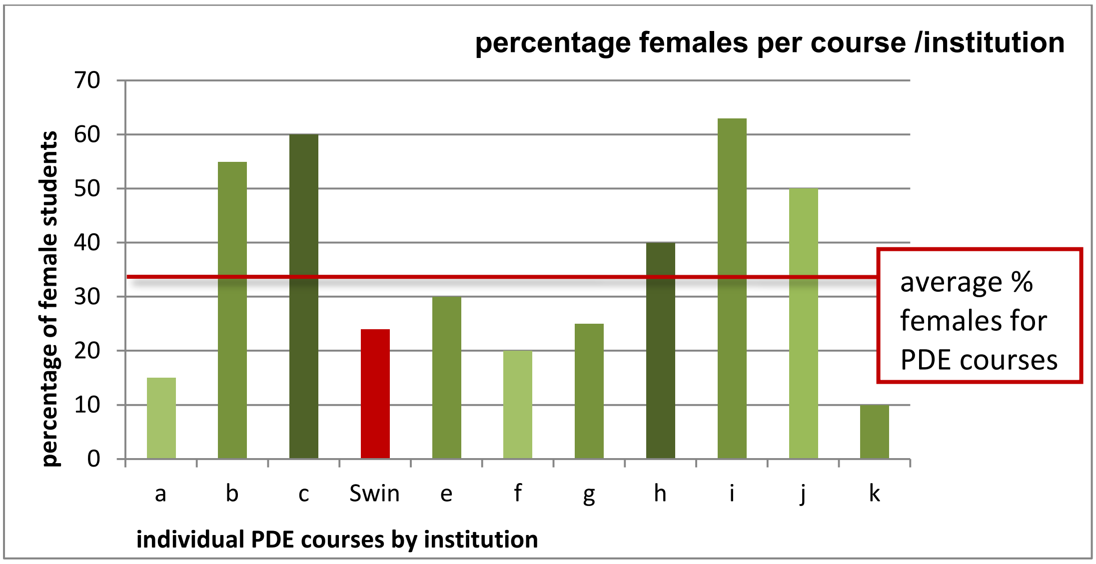

Figure 2.4: PDE student demographics – female enrolments as a percentage of annual enrolments (data source: PDE Curriculum Benchmarking Survey 2010)

Globally, female student ratios are consistently high with an average female ratio of 36 percent across the surveyed courses (Figure 2.4). These ratios are significantly higher than the global female averages for engineering education;

- United Kingdom 15% (UKRC 2010),
- USA 20 % (National Research Council Committee on Women in Science 2010),
- Australia 14% (Engineers Australia 2008), and
- Europe 20% (Eurostat)

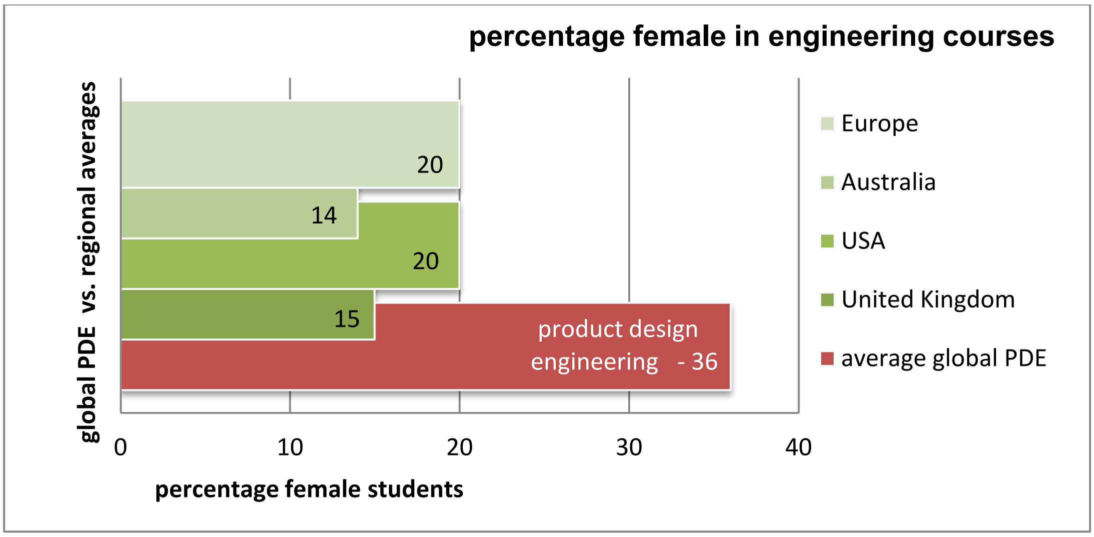

Figure 2.5: female student percentages in global engineering
(data sources: UKRC, National Research Council Committee on Women in Science, Engineering and Medicine , Institution of Engineers Australia, Eurostat , PDE Curriculum Benchmarking Survey 2010)

It is evident that the Product Design Engineering curricula globally outperforms other areas of engineering education in its ability to recruit female students. In Australia, the Swinburne PDE course has female ratios almost double the national engineering average, whilst in Scandinavia the surveyed PDE courses had female numbers almost three times the European engineering average.

This data implies a tendency for females (who may be interested in engineering) to gravitate towards new models of engineering education, particularly those with a broader and more human-centred curriculum, as observed by John (1995). The trend towards product design curricula is evidence of a renewed female interest in engineering that is bypassing more traditional engineering curricula.

2.9 Student retention

The curriculum survey indicated that retention rates for Product Design Engineering students are universally high, particularly among female students; suggesting that students are enjoying and valuing the curriculum.

All of the surveyed institutions had low 'failure to complete' rates, with a global average of only 9 percent of male PDE students failing to complete their course (to gain qualification), whilst only 2 percent of global female students not completing their PDE studies. (refer Figure 2.6)

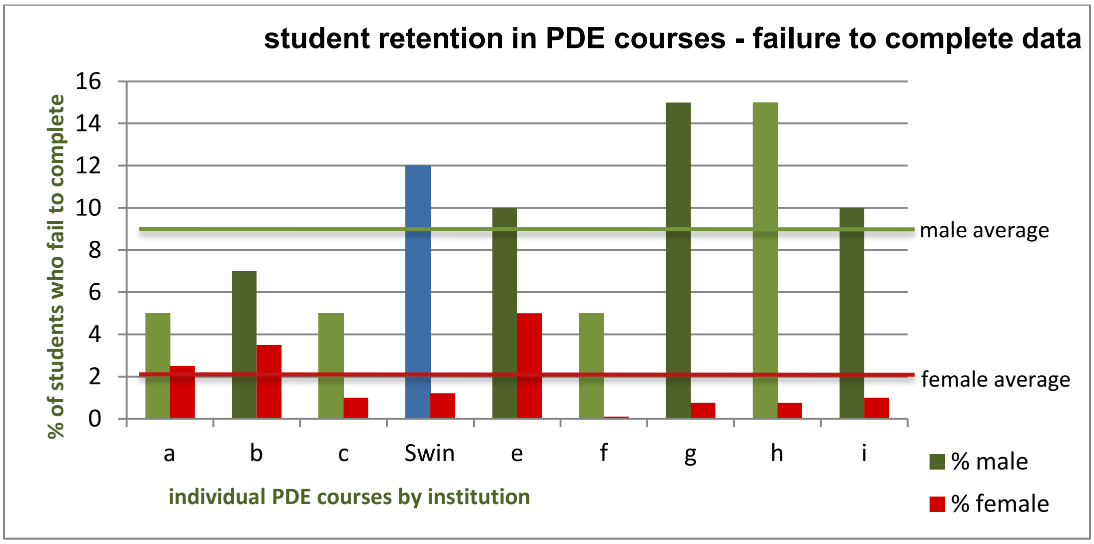

Figure 2.6: Student 'failure to complete' percentages in global PDE courses (data source: PDE Curriculum Benchmarking Survey 2010)

These 'failure to complete' figures are universally low in comparison to other engineering courses at the surveyed institutions. 57 percent of the surveyed program coordinators indicated that their PDE course had higher retention rates than other engineering courses within their institution, with only 14 percent of PDE courses recording lower retention rates than their faculty average. (refer Figure 2.7)

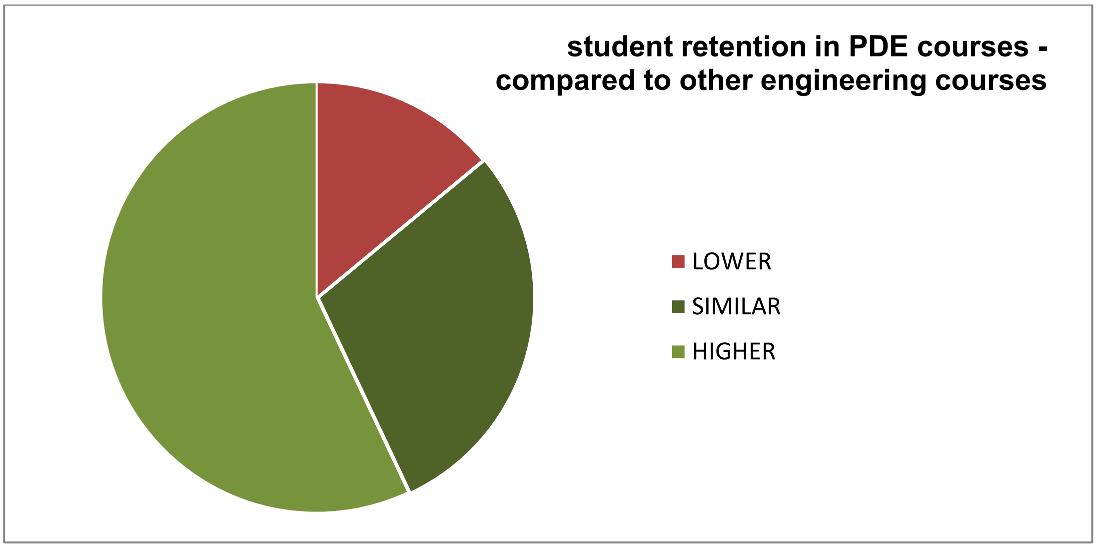

Figure 2.7: Student retention in global PDE courses compared with other engineering courses (data source: PDE Curriculum Benchmarking Survey 2010)

This data suggests that the PDE curriculum, whilst being attractive to a student cohort that would not normally consider studying engineering (especially females and the highly creative), also has the ability to then retain this diverse student cohort, through to course completion.

It could be assumed that a multidisciplinary program that requires students to learn and gain proficiency in two disparate professions, would by its nature be more demanding on students; leading to lower student retention and higher failure to complete rates; yet that is not the case with Product Design Engineering.

It could be argued that, despite a higher level of course complexity, the integration of design skills and critical environmental and social agendas into the engineering curriculum, has 'humanised' the engineering curricula, greatly influencing both the initial appeal of the PDE curriculum and the sustainability of that appeal for the course duration.

2.10 Curriculum

2.10.1 Multidisciplinary course content: design-engineering subject ratios

The Product Design Engineering curriculum has been described as multidisciplinary; a bend of mechanical engineering and industrial design. Investigation into course structures reveals that all of the surveyed courses are truly multidisciplinary with a relatively even balance between the weighting of design and engineering content.

Typically, design occupies about 41 percent of curriculum content (of the surveyed courses), with engineering averaging 46 percent. The remaining curriculum is occupied with non-core subjects such as electives and minor streams of study (which may be from other discipline areas or extension streams in engineering or design.

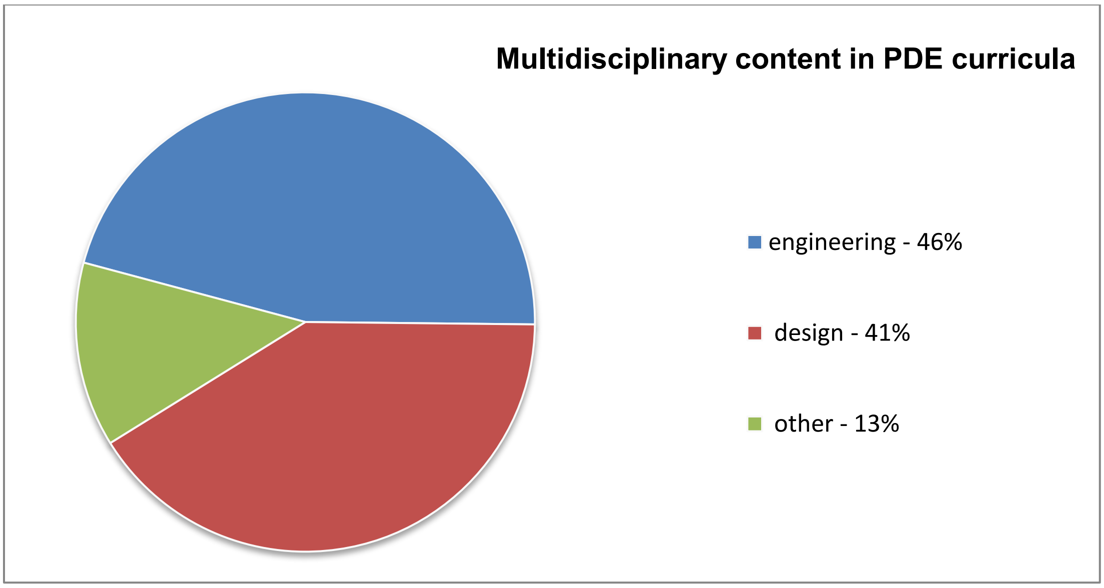

Figure 2.8: Engineering - Design balance averaged across surveyed PDE curricula: (data source: PDE Curriculum Benchmarking Survey 2010)

Although design content ranged from 25 to 60 percent, engineering typically dominated with 72 percent of the respondent courses indicating that engineering (represented by red columns in Figure 2.9) as an equal or larger curriculum component than design (shown in green). Whilst there is variation in the course weighting of the multidisciplinary components from course to course, it is apparent that there is a commonality of intent within the surveyed Product Design Engineering pedagogy; these are engineering courses with significant design content.

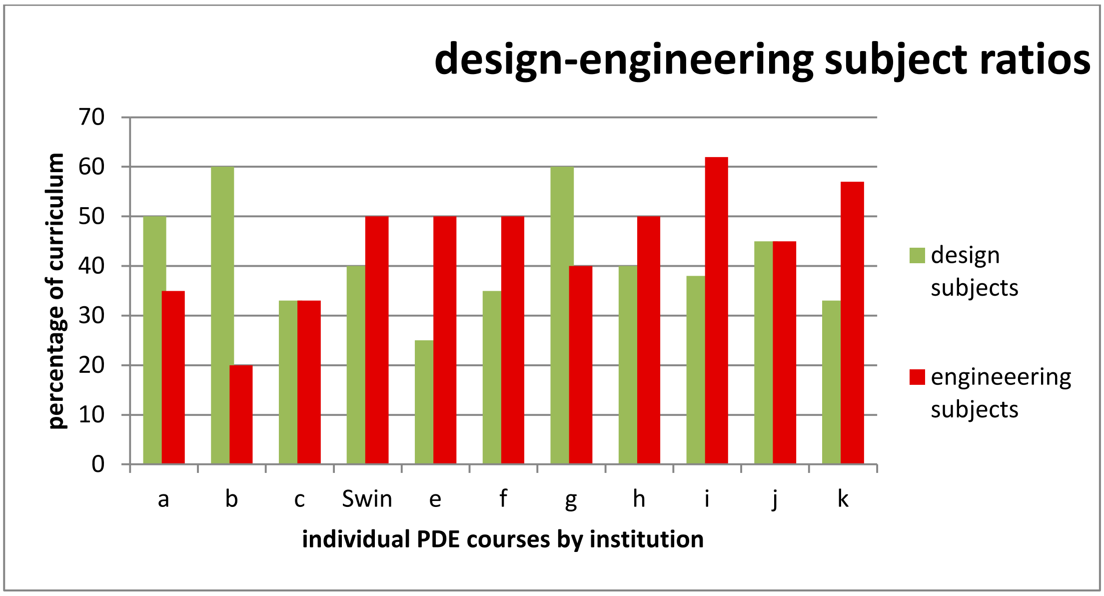

Figure 2.9: Multidisciplinary content (engineering - design balance) by institution (data source: PDE Curriculum Benchmarking Survey 2010)

It was unexpected that some courses (in particular the institutions marked 'b' and 'g' in Figure 2.9), would have such high design content. This warranted further investigation of that course's curricula, which revealed variation of interpretation of what constitutes a design or engineering subject. Mechatronics and Ergonomics were identified as design subjects, however Mechatronics is an engineering discipline, and Ergonomics or Human Factors teaching in engineering programs is more rigorous and scientific, compared to the user-centred design teaching common in industrial design education. By my interpretation, the balance for that institution was closer to a 40% engineering: 50% design ratio which is more consistent with other courses. The engineering content, whilst including a significant amount of mathematics, mechanics and physics (fundamental engineering), neglected the in-depth engineering application found in most Product Design Engineering courses: such as thermodynamics, fluid dynamics, machine design and advanced manufacturing systems.

This highlights the difficulty of developing multi-disciplinary curricula. A balance must be found between providing sufficient depth of engineering content, whilst allowing space for the inclusion of design content. In many cases this is achieved by varying the delivery of engineering subjects (away from purely theory-based models to more experiential learning) through the inclusion of a design project outcome or delivering significant engineering content and expectations into design subjects. These subjects become difficult to quantify as either design or engineering content. It is felt that some of the statistical variation exposed by this survey is indicative of differing interpretation (or ownership of subject delivery within institutions) rather than distinctive differences in content ratios.

In cross faculty programs (e.g. Swinburne) and cross institutional PDE programs (e.g. Glasgow School of Art/University of Glasgow), it is relatively easy to quantify what is engineering or design content, as design subjects are offered by a different institutional groups. However the distinction between what is engineering or design content is less clear when all subjects emerge from the same faculty.

2.10.2 Curriculum Delivery

Delivery of the different course aspects is therefore important, not just with content definition, but with depth of knowledge, relative importance of skills development and ownership of critical agendas.

Multidisciplinary programs offered though a single faculty (whilst most common) can be problematic as there is greater potential for one discipline to dominate the curriculum, diluting the potential for students to achieve a truly multidisciplinary methodology. Likewise, inter-institutional offerings (i.e. from two different institutions) can suffer from a lack of cohesion and poor coordination. This is not to suggest that inter-institutional delivery cannot succeed, rather that there are increased barriers to successful implementation and sustainability.

For multidisciplinary programs, such as Product Design Engineering, to succeed (when professional or institutional rivalries exist within the partnership) there must be significant understanding of, and respect for the others discipline. Without cross-integration of curriculum these courses can easily slip into ‘double-degree’ mode where the different elements of the course (in this case design and engineering) are delivered in parallel, limiting interdisciplinary learning and professional potential.

The surveyed Product Design Engineering courses were mostly single faculty delivery (59 percent) with inter-faculty collaboration occurring in 29 percent of surveyed courses. Only 12 percent of courses were co-offerings from different universities, highlighting the difficulties of inter-institutional collaboration (refer Figure 2.10)

The predominance of single faculty delivery owes much to the origins of the PDE discipline, where uptake of this style of curricula has occurred in industrial cities where manufacturing industries were well supported by engineering schools.

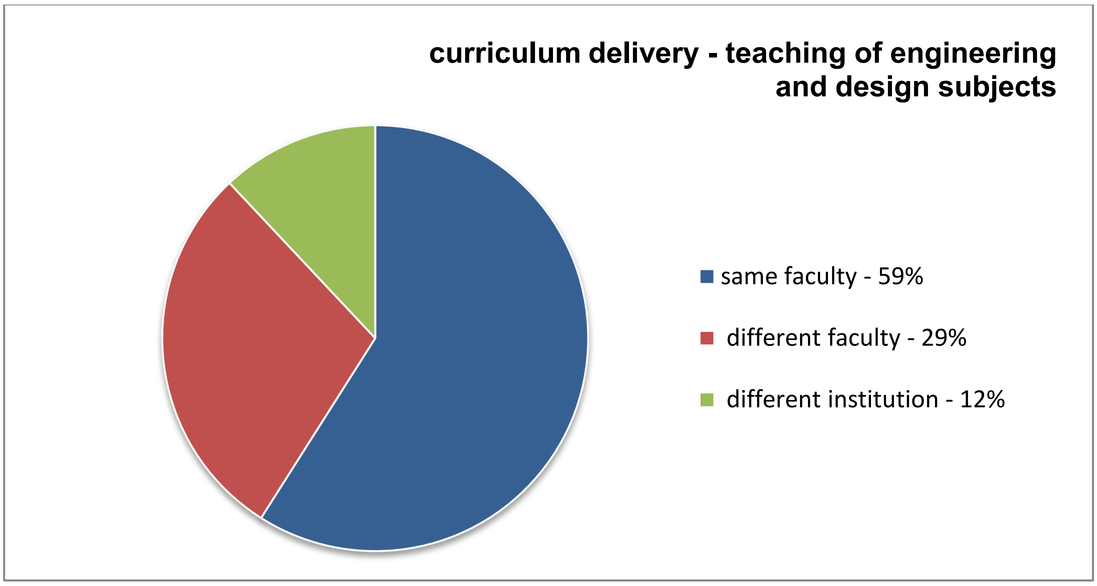

Figure 2.10: Curriculum delivery - teaching origin of engineering and design subjects: (data source: PDE Curriculum Benchmarking Survey 2010)

2.10.3 Cross cultural content integration and delivery

As discussed earlier, it is essential that the traditionally disparate elements of the multidisciplinary PDE curricula are integrated consistently rather than simply co-existing. Students need exposure to differing approaches to design, problem solving and resolution techniques through immersion in both disciplines. This is critical if they are to be truly multidisciplinary in approach. Consequently, the survey asked responders to briefly explain how engineering and design culture is integrated into their course structure.

From the diverse and detailed responses to this question, it has been possible to identify eight significant common methods deployed to integrate the culture of both disciplines into the course structure and delivery, as follows:

- cross faculty learning - e.g. content jointly delivered by different faculties
- design subjects / design projects - e.g. specific design learning
- multidisciplinary teaching - e.g. integrated/cross disciplinary teaching teams
- industry engagement/collaboration - e.g. industry involved in student projects
- student team integration - e.g. multidisciplinary student teamwork
- shared subjects with other design and engineering disciplines
- integrated content - e.g. engineering outcomes expected in design subjects

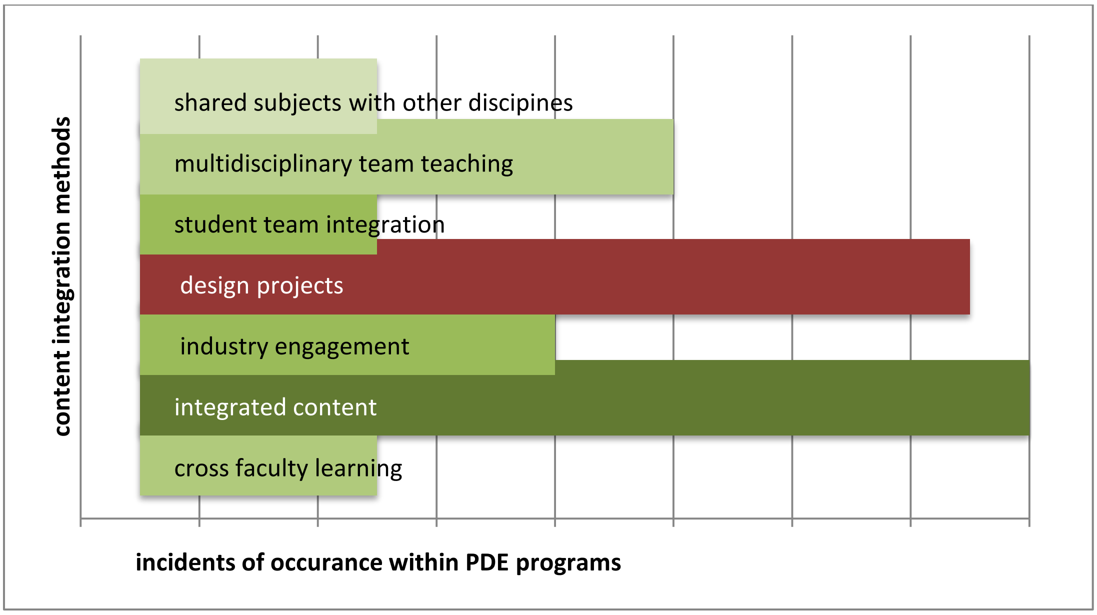

Figure 2.11: engineering and design content and cultural integration in PDE courses (data source: PDE Curriculum Benchmarking Survey 2010)

It appears evident (in Figure 2.11) that the main areas of cultural and content integration are through integrated content delivery and design projects (where students apply engineering knowledge to a design outcome).

Often it is the final year 'capstone' project that allows students to fully express their integrated design and engineering skills. Interdisciplinary teaching teams also contribute significantly to the learning experience, as does industry engagement.

Also evident is that, whilst a range of approaches are used, there is significant commonality of intent in the delivery and integration of the design and engineering disciplines. All courses use deliberate structural integration (including curriculum, teaching methodology, project work and industry collaborations) to ensure that students are exposed to the culture of both disciplines.

Critical to developing a truly multidisciplinary professional is this integration of curriculum content and delivery between the different disciplines. Failure to achieve cross discipline integration may result in either:

- one discipline dominating the student's process, limiting their ability to achieve multidisciplinary parity and broadness and diversity of approach
- a lack of connectedness between the disciplines – often evident in double degree and T-shaped courses (which are usually sequential, or parallel learning models – lacking cross-content integration)

There was evidence that 88 percent of the surveyed courses have successfully integrated the content and delivery of the design and engineering subjects in some way, as articulated below by the program coordinators:

- "design issues are now considered engineering issues"
- "design emphasised across all course aspects whether engineering, technical or design"
- "parallel teaching of technical (engineering) subjects and design projects that apply that knowledge"
- "cross-discipline deliverables within projects (i.e. engineering calculations, analysis and validations required in design outcomes)"
- "delivery is not separated"

Design subjects are typically taught in an experiential learning / project based learning model. It was apparent from the written responses that the design projects offer the most suitable (and thus common) solution to content integration. They afford the opportunity for projects that require both design and engineering submissions, supported by multidisciplinary teaching teams.

This is supported by the survey data with 94 percent of responses indicating that engineering science is incorporated into design teaching and design project outcomes. It appears common for students to be required to complete full engineering calculations, analysis and specification and to address engineering standards in their design subject outcomes.

It seems rare for integration of design to occur within the engineering subjects; this is mostly due to the requirement for technical and scientific theory-based learning and a lack of curricula flexibility due to accreditation requirements from engineering regulatory bodies. It is apparent that whilst significant curricula content can be allocated to design subjects (as long as they contain engineering content and input), the teaching of engineering theory is closely monitored by engineering regulatory organisations responsible for accrediting curricula.

This is reflected across PDE curricula from all institutions with 76 percent of PDE programs using shared engineering subjects common to other disciplines; in only a few cases has specific engineering content been developed for the PDE course.

Swinburne is one institution that has some unique PDE specific engineering subjects. This is due to PDE graduates not requiring significant depth of knowledge in specific areas of mechanical engineering e.g. thermodynamics or fluid dynamics. New curricula such as the combined subject ‘Thermofluid Systems’ (which replaced two separate subjects) have been developed, develop an understanding of the basic principles of these specific areas, whilst freeing up content area for the inclusion of the design subjects. This allows opportunity for greater integration between key design and engineering curricula.

With the exception of the two institutions that start design curricula in the second year, the remainder of the surveyed programs commenced design studies in the first year. This early engagement with design allows full development of design skills and creative processes, opportunities to develop genuine multi or interdisciplinary abilities and aids in the development of flexible and adaptable graduates.

2.10.4 Developing design skills and creativity

One of the key skills of creative design and innovative engineering is the ability to articulate thoughts and develop a reflective practice through the sketching process. Verstijnen and Hennessey (1998) found that the skilled sketchers benefited from the externalisation of mental imagery, whilst Bucciarelli (2002) notes that sketching is considered part of the language of design. Thus, emphasis on drawing ability can be seen as a key indicator of a focus on the acquisition of critical design skills, rather than a tokenistic inclusion of design curricula.

Unfortunately, whilst many mechanical engineering programs state that they focus on design and creativity, it is difficult to find evidence of drawing/sketching ability amongst engineering graduates. Yet without drawing acumen (i.e. perspective sketching), engineers can struggle to communicate design intent quickly and efficiently, resorting to digital processes (i.e. 3D CAD modelling) to visualise ideas.

It is considered essential that Product Design Engineering graduates are proficient at sketching, as typically they will be employed in industries that value (and depend on) these skills. The sketching ability of PDE graduates is a key skills differentiator from other engineering disciplines.

The research finding support this with course leaders commented that drawing was:

- "absolutely essential,"
- "a key part of the design thinking process" and
- "a fundamental link to creativity."

94% of the surveyed PDE programs (see Figure 2.12) require their graduates to be fluent and proficient at drawing, with 81% requiring this proficiency to be acquired earlier in their studies, not just by graduation. The only surveyed course that considered sketching to be 'not essential' was one of the 'T-shaped' engineering courses where the design major occurred late in the course. This program is not actually a PDE course, but was included in the survey for comparative purposes. It appears that drawing and creativity are key indicators of Product Design Engineering as a unique engineering discipline.

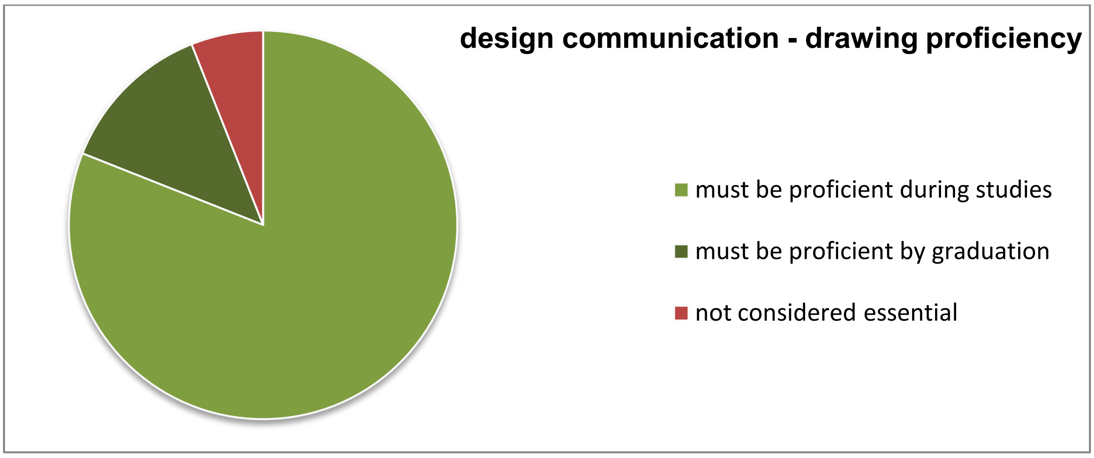

Figure 2.12: Expectations of drawing proficiency
(data source: PDE Curriculum Benchmarking Survey 2010)

Product Design Engineering students are also expected to be proficient designers and comfortable with ill-defined problems and creative and innovative. The experiential learning that occurs through the design project (often with 'wicked problems' to be addressed) creates opportunity for creativity and confidence to be developed; resulting in experienced design practitioners.

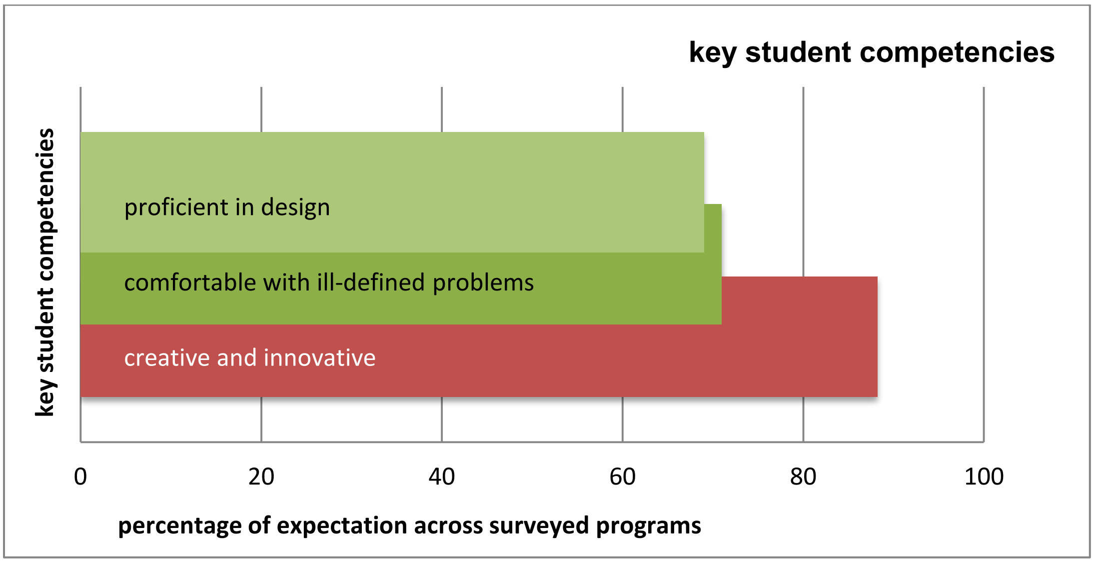

Figure 2.13: Expectations of key student competencies
(data source: PDE Curriculum Benchmarking Survey 2010)

As shown in Figure 2.13, the curriculum survey indicated that creativity and innovation were the most highly valued and expected student traits in PDE courses. This was not unforeseen. However it was surprising that 30 percent of the surveyed courses did not include 'proficient in design' as a key expectation; a result that required further investigation. It could have been expected in a survey of multidisciplinary engineering/design courses, that design proficiency would emerge as a key expectation of all students. Indeed it is inconceivable that a product 'design' course would not expect their students to be proficient designers.

An analysis of the individual responses from the courses that did not rank design proficiency revealed that two were T-shaped engineering courses, whilst the rest were PDE courses delivered solely though engineering faculties. Whilst this does not fully explain the unexpected result, it is possible that the survey results are indicative of a preference within engineering faculties towards engineering science, at the expense of design.

The structured and deliberate fostering of creativity is an essential differentiator between Product Design Engineering and other engineering disciplines. It is identified through this curriculum benchmarking survey as an essential student and graduate competency with 88 percent of responders expecting that their students to be creative and innovative. How this achieved, deserves further consideration (refer Figure 2.14).

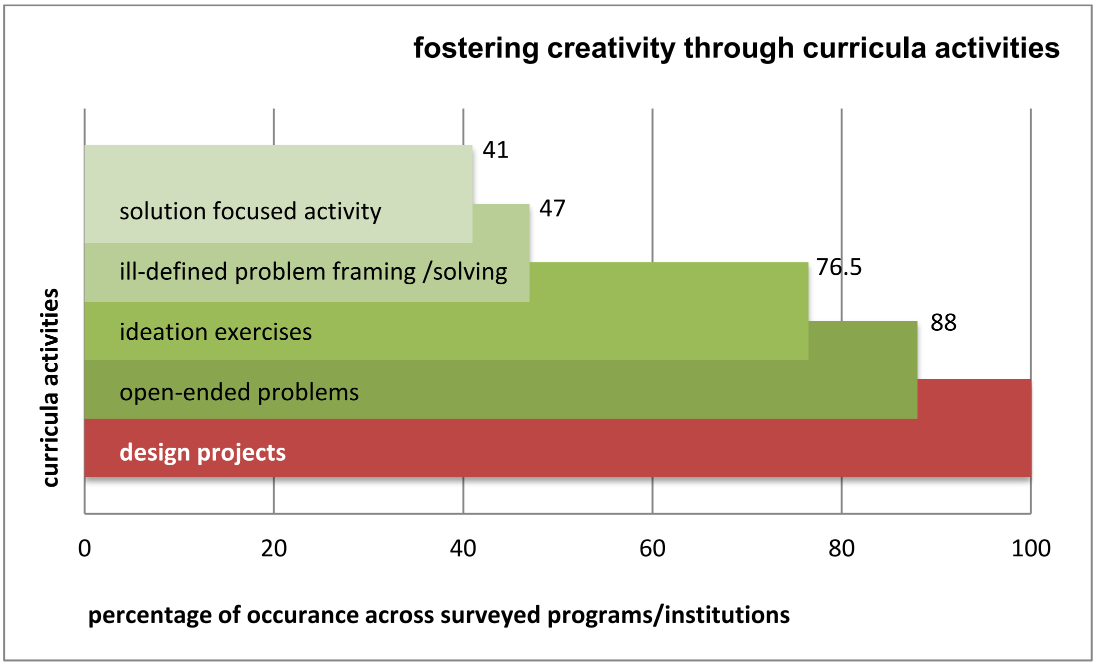

Figure 2.14: Curricula activities common in the fostering of creativity
(data source: PDE Curriculum Benchmarking Survey 2010)

In the surveyed PDE courses, creativity is specifically fostered in both design and engineering subjects of 65 percent of the programs, with the remainder expecting creativity to be fostered purely in design curricula.

Most commonly, it is the design project, in both design and engineering subjects, which provide the environment for the development of creativity, followed closely by open-ended problem solving (88%) and ideation exercises (76%). This aligns with the literature. "The easiest vehicle for promoting creativity and for developing the student's decision making ability is the design project" (Eekels 1987, p. 266).

Interestingly, when so much has been written regarding the 'wicked problems' that design graduates will face (Rittel and Webber 1973; Buchanan 1992), only half (47%) of surveyed programs specifically utilise ill-defined problem framing and solving as a means to foster creativity, although the design projects may address this.

2.10.5 User-centred design

One of the criticisms of engineering curricula, in particular mechanical engineering, is that it focuses solely on the science of engineering rather than preparing students for the practice of engineering (Dym et al. 2005). In this context it has been observed that 'engineers design for machines, whilst designers design for people.'

The Product Design Engineering curricula seek to resolve these issues through the curriculum inclusion of user-centred design (Norman 1988) and universal design (Mace et al. 1991). The intent is to prepare these engineers with user understanding and empathy so that the needs, wants and limitations of end-users are given appropriate attention throughout the design process, ensuring that the product is optimised for the user and the context in which it will be used.

The focus on user-centred design is evident throughout the global PDE curricula. The curriculum survey found that 94 percent of the surveyed courses specifically teach the principles of human-centred or inclusive design, and that their student projects require students to address both user considerations and functional requirements, rather than focus solely on technical aspects. (refer Figure 2.15)

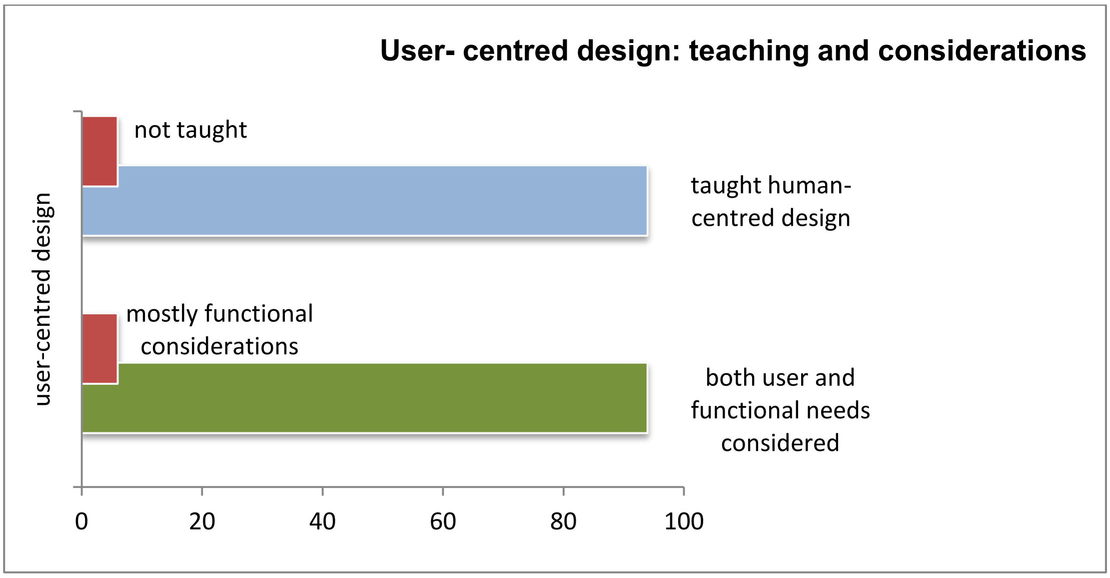

Figure 2.15: A focus on user-centred design
(data source: PDE Curriculum Benchmarking Survey 2010)

This emphasis on user-centred design differentiates Product Design Engineers from their curriculum-sharing mechanical engineering colleagues, as they move away from mostly functional considerations towards a more holistic and human-centred approach, more suited to new product development.

2.10.6 Critical curriculum agendas

The consistent PDE curricula focus on user-centred design is also apparent in a survey question that asked responders to identify critical curriculum agendas; those which informed students' design processes and outcomes. The survey results suggest a widespread emphasis on user-centred design in PDE curricula with user-centred design the most common project outcome expectation, as shown in Figure 2.16.

As discussed earlier, the inclusion in the curriculum of critical design agendas such as socially responsible design (SRD), cultural understanding and socio-economic factors as drivers for design direction and product resolution, are also evident in all of the surveyed PDE courses (Figure 2.16). This is evidence of curricula intent across the diverse PDE pedagogy, which aligns with critical expectations of the product design industry and engineering regulatory associations.

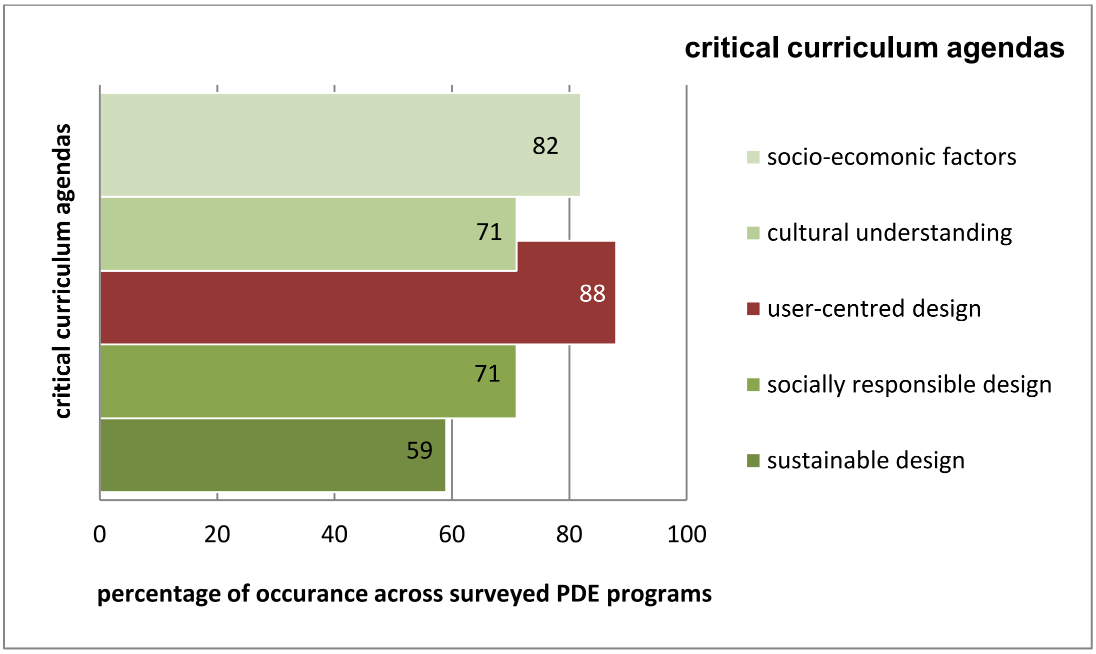

Figure 2.16: Critical curriculum agendas in PDE programs
(data source: PDE Curriculum Benchmarking Survey 2010)

Perhaps surprising was the lowest score; for sustainable design. It had been expected that this would the common denominator in engineering design curricula, as a global area of concern that attracts mainstream media attention on a regular basis. However, only 59 percent of surveyed courses required students to know and apply sustainable design principles to their designs. Whilst this statistic is not ideal, it correlates with the findings of a survey of industrial design courses in Australia where Ramirez (2006) found that 61 percent of courses integrated sustainability into their curriculum, through either dedicated courses or studio projects.

Perhaps this result highlights the slow rate of adaptation/uptake in engineering curricula, or it could reflect regional or institutional values. Whatever the reason for the omission of sustainable design as a key project outcome, it is suggested that those courses are not adequately preparing their student for 21st design challenges, in particular the future impact of carbon taxes, mandated responses to climate change, emerging green technologies and the need for clean (and closed loop) energy sources. It is imperative that engineering graduates are fully cognisant of the potential impact of their professional activities, and possess the appropriate knowledge and ability to make sustainable design decisions for all areas of the product life cycle.

Engineering faculties are obligated under course accreditation guidelines to meet sustainability objectives and address the requirements of engineering regulators including Engineers Australia, the US National Science Foundation (NSF), the American Association of Engineering Societies (AAES), the Royal Academy of Engineering (RAE), the Engineering Council UK and others.

"Universities in particular, and training managers as well, have a responsibility to deliver to the world graduates and qualified engineers who understand sustainable development and can deliver significantly more-sustainable solutions for society" (The Royal Academy of Engineering 2005, p. 45)

2.10.7 Industry involvement in curriculum

"Industry involvement in engineering education improves the relevance of education, better prepares students for employment, provides industry with a better qualified workforce, and creates synergy between industry and academia." (Lewis et al. 2006, p. 591)

As a practice driven curriculum, the Product Design Engineering course must, by necessity, engage with industry to ensure teaching maintains industry relevance and to facilitate opportunities for students to develop real-world understanding of professional practice. The curriculum is industry relevant and the involvement of practising designers and engineers in the delivery of teaching, or in leading projects adds specific relevance and creates aspirational pathways for students.

Typically, Product Design Engineering courses are highly engaged with industry, usually in multiple modes. As can be seen from the findings shown in Figure 2.17 below, a wide range of industry engagement models are utilised by PDE courses. The survey data indicates that most programs typically have two to three (average 2.7) different industry involvements in the development and delivery of the curriculum.

The common method of industry engagement for PDE courses is through industry-based learning, typically in the form of internships, with 65 percent of surveyed programs providing students with the opportunity to work directly in industry during their studies.

The curriculum benchmarking survey revealed that 59 percent of the surveyed PDE courses employed industry personnel to contribute to the curriculum, through direct involvement in teaching and utilised industry-led projects. In addition, a majority of programs (65 percent) used industry placements or internships to reinforce 'real world' learning and understanding of industry practice.

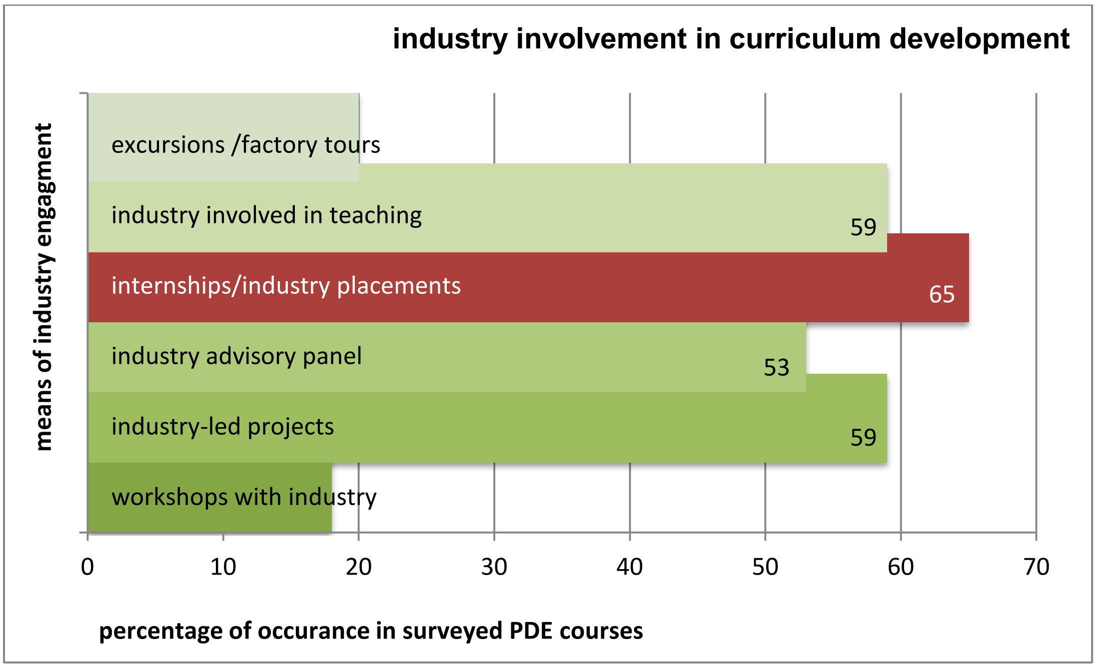

Figure 2.17: Means of industry involvement in PDE curricula
(data source: PDE Curriculum Benchmarking Survey 2010)

59 percent of programs utilise industry-led projects which are either 'live' (current) projects or other real world projects often given to students when R&D resource allocation is not a major priority. Student projects affords the industry partner new creative possibilities as students are not encumbered by company policy, entrenched methods of working, company hierarchies of roles and responsibility and pre-determined or well established processes. This can lead to greater innovation and new insights. The students' benefit from the relationship by being better prepared for the practice of engineering, through the opportunity to balance theory with real world practice (Dutson et al. 1997), enhanced by industry critique and the possibility of the project progressing beyond university submission to a manufactured outcome.

Industry-led projects require university and industry cooperation and a commitment to an ongoing relationship. These projects can result in extra pressure on students and staff; however the opportunity for students to engage with potential employers, work on actual projects and measure their capabilities against industry criteria is extremely beneficial. The final year capstone project (discussed in Chapter five: *Collaboration with industry)* examines barriers to successful collaboration with industry from both a learning and design outcome perspective.

Industry involvement in teaching activities is particularly useful. Using industry professionals in classes to provide content delivery, tutoring or specialist teaching support has many benefits, both to student learning and course relevance. The main benefits of direct industry involvement in teaching activities are that:

- practice-based learning is enhanced
- working with professionals is aspirational for students
- career pathways are confirmed
- employment opportunities emerge
- graduate attributes are aligned with market expectations
- graduate confidence increases through comparison and real-world feedback
- procedures and technologies remain up-to-date with current industry practice
- future trends in industry practice are identified

In Australia, the Swinburne Product Design Engineering program utilises course graduates in an 'engineering support' role in all design studio sessions. This has proven to be advantageous, achieving several objectives. Firstly, it satisfies Engineers Australia's accreditation requirements, for a qualified engineer to be involved in all areas of teaching. Secondly, the engagement of former students (now with 3-5 years of industry experience) in tutoring and technical support roles has benefited the application of engineering science to the design project outcomes.

In addition, it has aided in defining a 'professional identity' for students uncertain as to their positioning within the product design and development environment. This is critical as multidisciplinary students can struggle to define whether they are an engineer or a designer and where they 'fit' in the new product development process. Whilst PDE graduates are capable of working in either design or engineering roles, they graduate into an industry and wider community that often seeks to categorise them within existing professional frameworks.

2.11 Course recognition in industry and community

The Product Design Engineering paradigm is still relatively new (compared to the established engineering disciplines). Since the first course commenced in 1987 the growth rate of this pedagogy has averaged approximately one new course per year. Twenty-five years later it is still a relatively unique profession and consequently suffers from low visibility, especially in the wider community.

Despite the success of Product Design Engineering graduates in the workplace, especially in product design and development, outside of these industries PDE is relatively unknown. As is evident (in Figures 2.18 and 2.19 where the highest values are highlighted in red), only a small proportion of schools understand the PDE profession, leading to difficulties in recruitment of school leavers. This is not helped by a lack of awareness of Product Design Engineering amongst the wider community, resulting in fewer students selecting PDE as an alternative career pathway to other engineering or design disciplines.

	not known	known, but not understood	known and understood	respected
industry	6%	17%	35%	41%
community	41%	47%	6%	6%
schools	12%	56%	13%	19%
engineering regulatory bodies	6%	35%	47%	12%

Figure 2.18: Data on PDE course recognition in industry and community (data source: PDE Curriculum Benchmarking Survey 2010)

With the exception of three courses (all with annual enrolment higher than one hundred students), the average intake of the surveyed courses is approximately thirty students per annum. Although PDE could be considered a bespoke course/profession with accordingly lower demand, the student intake is extremely low compared to the curricula from which it is derived (industrial design and mechanical engineering).

This is indicative of either a shortage of school leavers with multidisciplinary creative and technical ability, or more likely, a low awareness of PDE as an educational and professional option. The curriculum survey points to the low discipline awareness as the mitigating factor.

Whilst PDE suffers from low visibility in the wider community, it has achieved recognition in appropriate employment industries. 76 percent of courses indicated that industry knew and understood (35%) or respected (41%) the PDE discipline, compared to only 12 percent awareness in the community and 26 percent in schools.

Of concern however, is data suggesting that only 12 percent of PDE courses felt that the engineering regulatory body responsible for course accreditation 'respected' the Product Design Engineering discipline. Whilst the PDE programs were accredited by those organisations, the contribution of these new curricula is not always appreciated within the entrenched value system of organisations bodies. There are also indications of an ingrained suspicion of designers within engineering communities, and some PDE graduates comment that initially they are not completely trusted by fellow engineers, due to their design training.

Figure 2.19 indicates the awareness of Product Design Engineering in industry and community, with the most common responses in each category defining the positioning as follows:

- in industry it is respected
- in the community it is unknown
- in schools it is known, but not understood
- in engineering regulatory bodies it is known and understood

The next step in the development of Product Design Engineering, must therefore be to increase the visibility of the discipline, both from an educational and professional perspective. Universities need to work closely to promote the discipline amongst the school community, whilst the success of PDE professionals needs to be widely publicised. This will serve to both promote wider community awareness, and to highlight the value of PDE to the relevant engineering regulatory organisations.

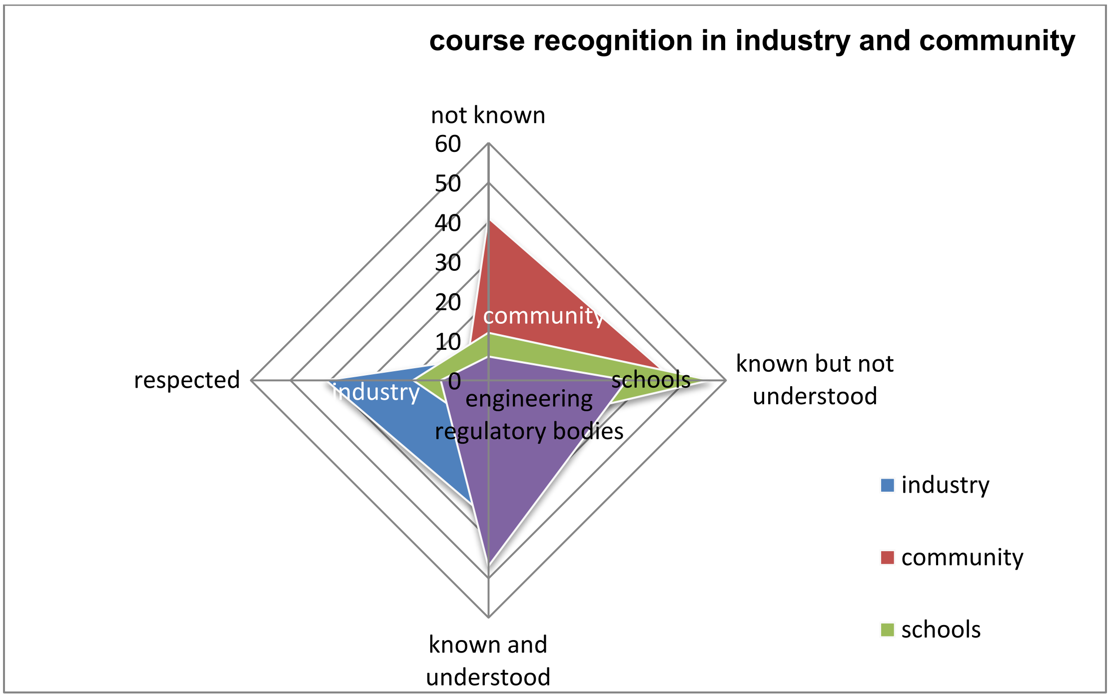

Figure 2.19: PDE course recognition in industry and community (data source: PDE Curriculum Benchmarking Survey 2010)

2.12 Relevance to industry

2.12.1 Key areas of commendation from industry

The 2010 PDE curriculum survey asked program coordinators to explain key areas where their course had received commendation from industry. Responses were wide ranging, but several key themes emerged from the survey; in particular

- recognition of creativity,
- industry relevance and graduate readiness,
- high employment rates,
- multidisciplinary skills, and
- international design competition success.

Figure 2.20 (below) indicates the consistency of commendation for industry relevant curricula. This is also reflected in higher than average graduate employment statistics, with coordinators stating that;

> "We have the highest rate of employment among national programs in industrial design and design engineering." and

> "Our graduates find jobs soon after graduation, or during their final project."

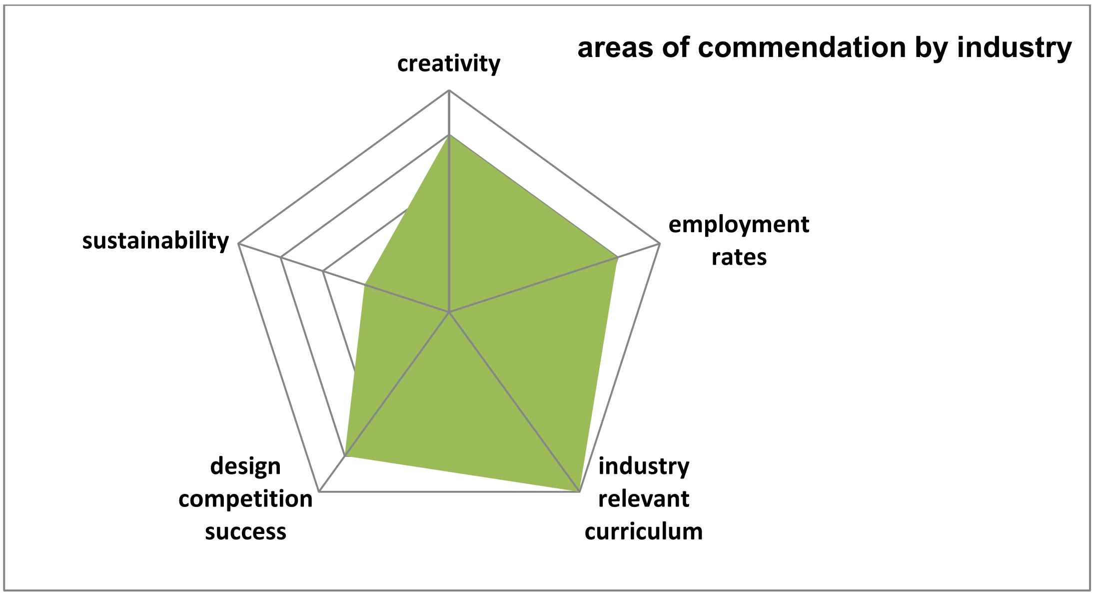

Figure 2.20: Areas of industry commendation for PDE courses
(data source: PDE Curriculum Benchmarking Survey 2010)

There is also evidence of wide-spread industry recognition of the creativity of the Product Design Engineering graduates. This is indicative of the success of design led-curricula that focuses on the fostering of creativity and emphasises innovation.

Other common responses indicated willingness for employers to be involved in student projects, workshops and internship programs, with program coordinators noting that:

> "We have a waiting list for industry sponsored projects and getting involved means that there will be an agreed form of payment."

> "Important industries typically seek PDE graduates and propose projects to be carried out by PDE workshops."

Many responses dealt with recognition of the multidisciplinary nature of PDE:

> "Our graduates are praised for their ability to bridge the gap between engineering and design, their team work and their ability to describe, handle and manage design processes and communication professionally."

> "AMSE Awards for skills, areas of coverage and creativity."

> "Industry welcomes the rationale of this cross-discipline course and that graduates are more aware of the technical aspects in design."

Also discussed were the leadership qualities and industry successes of Product Design Engineers, including this response:

> "PDE graduates are also responsible for establishing some of the most successful Design Engineering agencies in the UK and beyond."

It is evident that although still a fledgling profession when compared to more established engineering disciplines, PDE has made an impact in industry and is recognised and respected for its contribution to product design and development. A strong demand for PDE interns and graduates plus the willingness of industry to engage in student projects, is indicative of the relevance of the pedagogy. This is further supported by examination of employment rates and graduate pathways.

2.12.2 Employment rates and graduate pathways

Examination of graduate pathways for Product Design Engineering reveals that graduates are highly successful in finding employment in their chosen field.

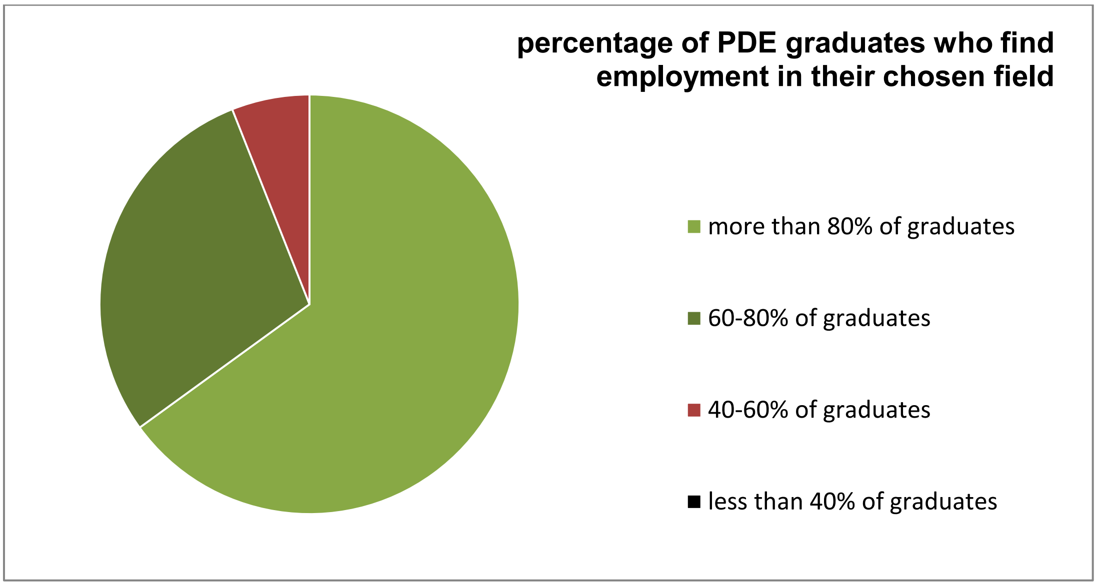

Figure 2.21: Percentage of PDE graduates who find employment in their chosen field (data source: PDE Curriculum Benchmarking Survey 2010)

Sixty-five percent of the surveyed courses indicated that more that 80 percent of their graduates found appropriate industry positions. The data (in Figure 2.21) reveals that the majority of PDE courses (94 percent, displayed in green) achieve rates of graduate employment that are higher than 60 percent, and that none of the courses recorded employment rates of less than 40 percent.

These figures are representative of both the industry relevance of the PDE pedagogy and the employability of its graduates. Many of the programs report almost full graduate employment with graduates often sourcing employment soon after or even during their final studies. Prior to the impact of the Global Financial Crisis, the Swinburne PDE course had five years of 100 percent graduate employment and for many years demand for graduates often outnumbered supply. The high employment uptake appears to result from the graduates' diversity of skills, broad knowledge base and multidisciplinary approach.

It is evident that they are exposed to a wide range of employment opportunities, with greater diversity of potential roles and environments than the single discipline mechanical engineers or industrial designers. However, the opportunities for Product Design Engineers are more than just the sum total of potential ME or ID positions. There is evidence that PDE graduates have been successful in creating roles and responsibilities (in new product development) that did not exist prior to the emergence of this curricula (refer 2010 employer interviews in Chapter 8).

2.12.3 Industry pathways for PDE graduates

The curriculum survey revealed that the Product Design Engineering curriculum facilitates a diversity of employment options; with only 12 percent of the surveyed programs focusing their curriculum towards specific industries (refer Figure 2.22).

The majority of courses report a wide range of employment options for Product Design Engineering graduates. However the most common graduate destination is the product design and development environment, an industry ideally positioned to take advantage of the skills diversity of PDE, and a traditional employer of both design engineers and industrial designers.

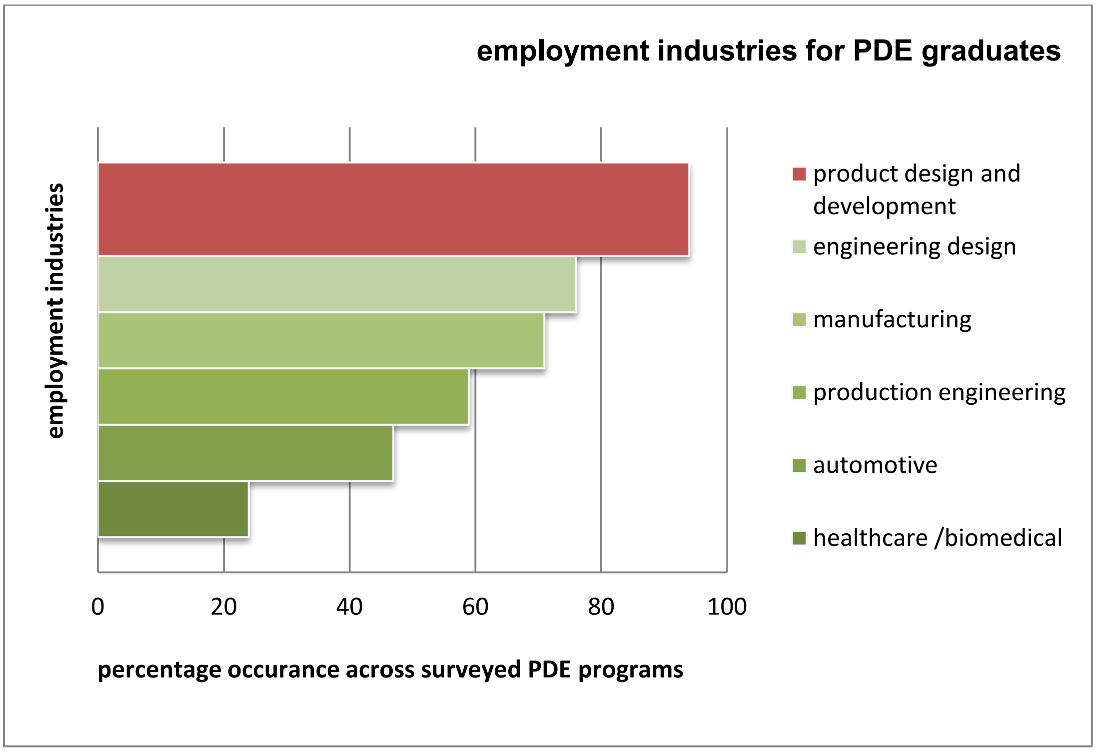

Figure 2.22: Industry pathways for PDE graduates
(data source: PDE Curriculum Benchmarking Survey 2010)

Many graduates also find themselves in what are customarily mechanical engineering roles, such as manufacturing and production and engineering design. Whilst they may lack some depth of knowledge in some areas of engineering science, they are able to successfully compete with mechanical engineering graduates for these positions, aided by an interdisciplinary approach that facilitates workplace communication, understanding and cohesion and additional skills.

It appears that their ability to understand and respond to user needs, and their creative design ability enhances their value and employability in manufacturing organisations who seek market share or productivity improvements through innovation. In difficult economic climates, the PDEs ability to respond to organisational demands by operating effectively in varying roles form conceptual product design to production engineering is viewed as an additional asset.

This diversity of employment potential raises the question of course definition. It is important to understand how the PDE courses promote their graduates to industry, and which skills and attributes categorise PDE in the eyes of the offering institutions.

2.12.4 Vocational positioning of PDE graduates

The curriculum survey revealed that Product Design Engineering graduates are promoted to potential industry employers predominately (77%) as multidisciplinary professionals who are capable in both fields; design and engineering. This aligns well with both curriculum intent and the rationale behind the emergence of the discipline.

There are other descriptors that get almost equal scores amongst the surveyed courses (as shown in Figure 2.23); designers with engineering (47%), product designer (41%) and engineers with design ability (also 41%). These descriptors are evidence of the lack of discipline awareness (identified early in this research) leading programs to revert to most easily understood, although less accurate, titles.

One third of courses (35%) also promote their PDE graduates as engineering designers, but this depiction falls short of defining the multidisciplinary nature of the profession. There are many design engineers whose education included design curricula, but whose methodology is purely engineering in approach.

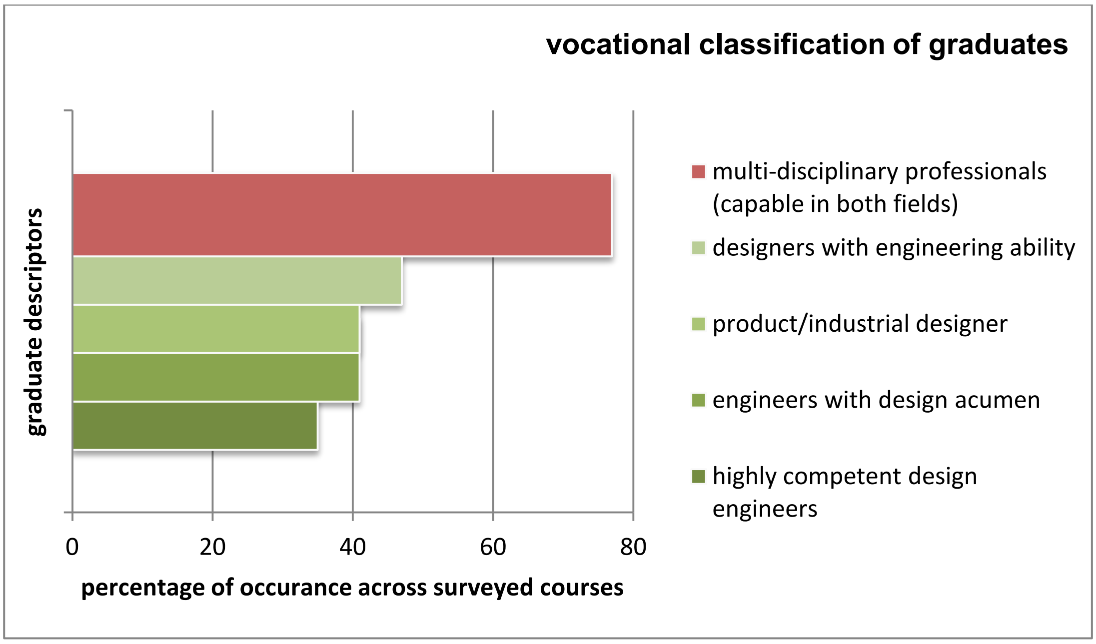

Figure 2.23: Vocational classification of PDE graduates
(data source: PDE Curriculum Benchmarking Survey 2010)

2.12.5 Expected PDE graduate attributes

Chapter One identified the required graduate attributes for engineers engaged in new product development, and their relative importance. This survey aimed to ascertain whether the skill sets of graduates from a global selection of PDE programs align with the needs of new product development, and the objectives of engineering regulatory and course accreditation organisations.

Figure 2.24 shows the seven major graduate attributes identified by PDE program coordinators,. The surveyed courses were relatively consistent in their identification of critical skill sets for Product Design Engineering graduates. Almost all courses (94%) identified creativity as an expected attribute, this followed closely by design acumen (88%) and engineering proficiency and human-centred design (both 83%) and responsibility (77%).

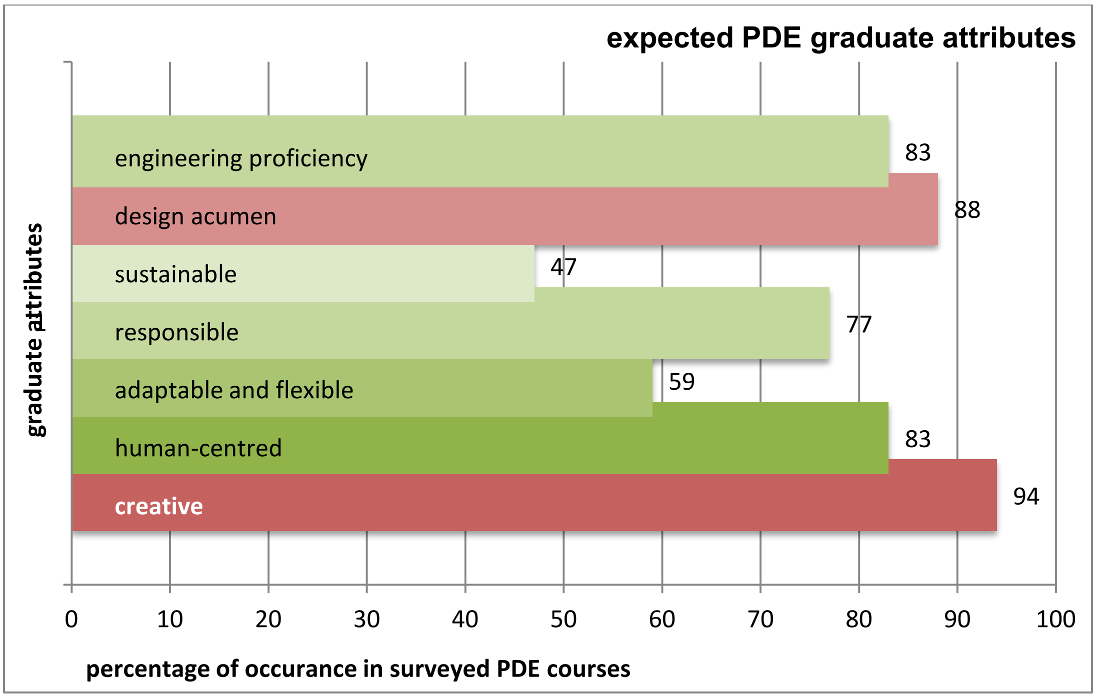

Figure 2.24: Expected PDE graduate attributes
(data source: PDE Curriculum Benchmarking Survey 2010)

Based on these research findings, it can be surmised that the key attributes of the Product Design Engineer can be defined (in order of importance) as:

1. creative,
2. a skilled designer,
3. a proficient engineer,
4. human centred, and
5. responsible.

This provides clear evidence of the alignment of global Product Design Engineering graduate attributes with the needs of new product development.

'Sustainable' was an expected graduate skill in less than half (47%) of the surveyed courses, however this is consistent with the examination of key curriculum aspects (see Figure 2.16) where sustainable design was only included in 59 percent of the surveyed curricula. It is evident that sustainability requires further pedagogical investment, if graduates are to be trained to assume leadership roles in reducing the environmental and social impact of new product development.

2.13 Classifying Product Design Engineering

As Product Design Engineering emerges from the integration of two disciplines that are typically disparate, it is interesting to define the key distinction between Product Design Engineering graduates and those from the more widespread design and engineering disciplines. Survey responders were asked to identify key points of differentiation when comparing Product Design Engineering graduates with the single discipline curricula graduates of Industrial Design and Mechanical Engineering. The responses are summarised below.

2.13.1 A comparison between Mechanical Engineering and Product Design Engineering graduates – quotations from Program Coordinators

In this section are direct text inputs from the PDE Program coordinators who responded to the survey. What is immediately apparent, when reviewing the responses, is the emphasis on the PDEs user-centred human and social approach, creativity and innovation, and open-ended problem solving ability. The PDE graduates are also considered “more rounded’ and capable across the entire product design process.

Figure 2.25 identifies the key characteristics interpreted from the text input responses that differentiate PDE graduates from those of mechanical engineering.

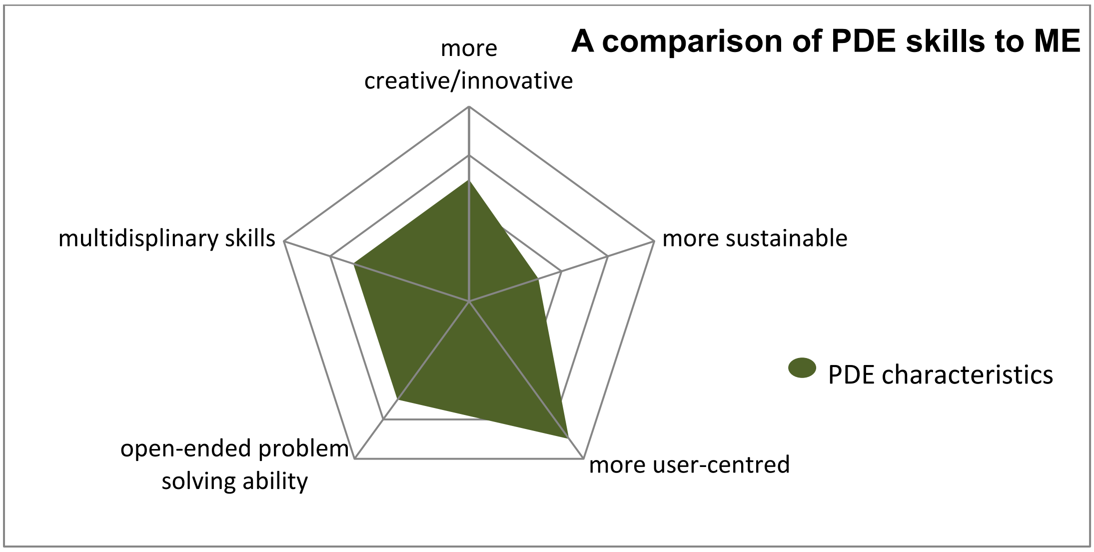

Figure 2.25: PDEs compared to Mechanical Engineers
(data source: PDE Curriculum Benchmarking Survey 2010)

When asked to define how Product Design Engineering graduates differed from Mechanical Engineers, the PDE Program Coordinators responded as follows:

> “Compared to other engineering graduates, Product Design Engineering graduates are better communicators, better project managers, more innovative and more sustainable.”

> “Product Design Engineers are mechanical engineers with design and innovation acumen.”

> “Our (PDE) students differ even more from the traditional mechanical engineers who mostly are very focused on specific functionalities and have no sense for what a product is or what the real needs of the consumer are. But of

course they (ME) have a deeper technical knowledge than our (PDE) candidates in certain areas."

"Although our PDE students get an engineering degree most of us (including the students) consider them industrial designers as well, as their basic approach is a very holistic one handling the fuzzy and soft aspects as well as the hardware related ones."

"They (the PDE students) cover all aspects of new product development from vague idea to successful market reaction, crucial for business and community. They will play the essential role in business development of technical oriented companies, for which they will often get the higher positions."

"Mechanical engineering is very different. A student trained in mechanical engineering can be involved in product design but highly unlikely that they will be able to perceive design problems and solutions as well as a PDE or ID trained design student. They are purely *mechanistic*."

"They (PDE) are more interested in solving the customer/users problem (than mechanical engineers)."

"The way our department approaches PDE is that this is an integrated discipline and does not replace Mechanical Engineering or Industrial Design. We would want to see a new breed of graduates emerge who would call themselves Design Engineers."

"The PDEs are more capable to cope with complex and open ended technical problems (no straight forward calculating) than the mechanical engineers; with an open eye for human involvement, environmental issues and international cultural aspects."

"But of course the PDE students differ in that they have the attributes of both disciplines. So as engineers they have the ability to present attractive (emotionally desirable) engineering proposals, and as designers, they have the ability to apply engineering analysis to determine optimal and cost-effective technologies.”

“(PDEs demonstrate) more creative innovation.”

“Mechanical Engineers solve machines as a technical system, but don’t include human and social factors.”

“(The PDEs with their) interdisciplinary skills and cross disciplinary liaison skills are more creative and human centred than Mechanical Engineers, and more flexible and adaptive than the MEs, and more industry ready than both ID and ME.”

(The PDEs are) are more rounded and considerate of others opinions and don't forget the requirements of the user. Industry also benefits from the 'two in one' approach; we often find PDE grads becoming the hub/go to person in the company/employer. There is also the qualitative/quantitative aspect of the PDE education. This is defining feature of the PDE approach.”

“(Product Design Engineers) tackle more efficiently multi-disciplinary problems in the design and development processes of complex products; they lead these processes, promote and implement innovation in engineering design; execute responsible engineering design by making optimal decisions by understanding and communicating with professionals from other discipline.”

These responses indicate a clear distinction between the ‘new’ Product Design Engineers and the traditional mechanical engineers, in particular the human and societal considerations, the complex or open-ended problem solving and the creativity. Also emerging from these responses is a greater capacity for the PDEs to communicate and liaise across disciplines and not surprisingly, a greater suitability for roles and responsibility in product design and development.

Amongst these positive accolades though, is the comment from one respondent that the mechanical engineers “have a deeper technical knowledge” than the PDE graduates. This is understandable as the Product Design Engineering curricula has had to lose some depth in engineering theory in order to accommodate design content.

This lack of engineering rigour was also identified by some industry employers as a potential weakness in PDE graduates. Interviews with PDE employers indicated that there are some in industry who feel that the ‘all-rounder’ PDEs sometimes lack the pragmatic and disciplined approach of a purely mechanical engineer. This may be problematic when the PDE graduate is employed in an entirely engineering capacity, or advanced engineering situations where they may have sole responsibility for engineering decisions. This issue and its relative importance will be discussed further in Chapter 8: *Industry Relevance*.

2.13.2 A comparison between graduates of Industrial Design and Product Design Engineering

Included in this section are direct text inputs from the PDE Program coordinators who responded to the survey question that asked them to distinguish between PDE and Industrial Design (ID) graduates.

As the product design and development environment is evolving to accommodate the emergence of Product Design Engineering, this is a critical distinction in the identification of this engineering discipline whose graduates often compete for employment directly against industrial designers.

Figure 2.26 identifies the key characteristics (interpreted from the text input responses) that differentiate PDE graduates from those of Industrial Designers.

Immediately evident is that the Product Design Engineers are seen as more ‘technically competent’ than the industrial designers. This is a recurring theme, supported by statements from industry employers (as detailed in Chapter 8). Whilst they may lack some creative or artistic ability when compared to industrial designers, the ability to incorporate technical considerations into design thinking is seen as a key distinguishing feature of Product Design Engineering.

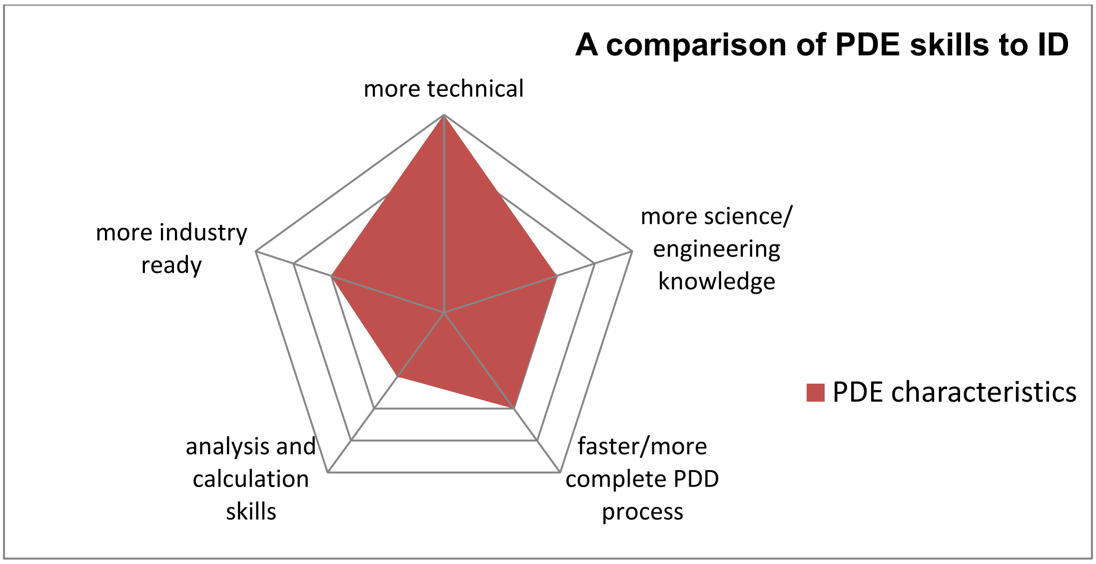

Figure 2.26: PDEs compared to Industrial Designers
(data source: PDE Curriculum Benchmarking Survey 2010)

The PDEs are also considered to be more industry-ready, with faster and more complete product design processes. This reflects their ability to work at both ends of the process, from conceptual design to technical resolution.

When asked to define how Product Design Engineering graduates differed from Industrial Designers, the PDE Program Coordinators responded as follows:

> “Compared to Industrial Design graduates, PDEs have more science and engineering knowledge, develop more complete product design outcomes and have the potential to achieve faster completion of product designs.”

> “The difference in comparison to traditional industrial designers is that our (PDE) students understand the language and methods of an engineer, and they are also able to calculate matters that an industrial designer would never do.”

> “They have more technical skill than industrial designers.”

> “Product Design Engineering graduates differ from Industrial Designers in that Industrial Design training is more focused on user, culture and socio-economic aspects. PDE graduates are more technology focused, can be considered as user oriented or user-centred as well, but are more focussed and capable in applying technology to design.”
>
> “Because of the prevailing functional requirements, PDEs are less focussed on the "nice" design then the average Industrial Designer.”
>
> “Industrial Designers don´t understand the engineering competences like physics, calculus, statistics, materials, resistance, etc.”
>
> “The Product Design Engineers are more technically proficient than Industrial Designers, and more industry ready than both ID and Mechanical Engineers.”

What is immediately apparent from these responses is that Product Design Engineering graduates (when compared to industrial designers) are considered by the surveyed program coordinators to be:

- more technically proficient
- ability to apply scientific and engineering knowledge
- more complete
- less focussed on purely aesthetic solutions
- more industry ready

This is supported by both the survey of Swinburne PDE alumni (refer Chapter 7) and the employer interviews (refer Chapter 8). Many of the PDE alumni commented that they had found themselves to be more technical and scientific than the industrial designers in their workplace, with a better understanding of manufacturing requirements; this was supported by industry feedback.

The comparison between PDE, mechanical engineers and industrial designers is a theme that is revisited in both the alumni survey and the employer interviews in the following chapters. This affords a three-way perspective between the curriculum intent, the resultant graduate attributes and the relevance to industry.

2.14 Conclusion

After extensive analysis of the data gathered from the survey, responses of seventeen Product Design Engineering program leaders, evidence emerges regarding the characteristics of Product Design Engineering; both as a pedagogy and a profession.

Based on the findings of the 2010 curriculum benchmarking survey, Product Design Engineering can be summarised as:

- a mostly engineering qualification that has experienced steady growth in global course delivery,
- a curriculum that is significantly more appealing to female students when compared to other engineering curricula, with high student retention,
- comprised of a relatively even mix of engineering and design content, usually taught within the same faculty,
- an integrated curricula with design projects and content integration utilised to develop methodological links between the disciplines,
- fostering creativity through design projects, expectations of drawing proficiency and open-ended problems,
- developing a strong user-centred focus with critical agendas such as cultural sensitivity, social responsibility and sustainability as key curriculum areas,
- a program with strong industry engagement though internships, teaching and industry-led projects,
- a discipline that is respected in industry but not well known or understood in the wider community, especially in schools,
- commended for industry-relevant curricula and design competition success,
- producing highly employable multidisciplinary graduates with a wide range of employment options,
- an engineering discipline that is more creative and user-centred, and superior problem solvers, compared to Mechanical Engineers,
- a creative NPD profession that is more technical than Industrial Design, and
- creative, human-centred, skilled designers and proficient engineers,

These graduate attributes align closely with the needs of industry, address concerns by engineering regulatory organisations, and reinforces the hypothesis that Product Design Engineering is an appropriate solution for specific needs of the new product development industry. Also evident in the research findings are commonalities of program intent, curriculum content and agendas, global appeal to female students, an emphasis on design skills including sketching, creativity, and industry relevance.

Product Design Engineering has emerged from this research as a distinct engineering discipline with specific skill sets, and a human-centred core. In this relatively new discipline, design and engineering skills have almost equal weighting in expected graduate attributes, and creativity is the most typically expected outcome.

This chapter has dealt with the response of PDE program leaders globally, and has identified the curriculum intent and delivery of Product Design Engineering and the key graduate attributes in comparison with other PDE disciplines.

The following Case Study 1 provides a detailed investigation into a specific Product Design Engineering course (in this instance Swinburne University of Technology) and shows how curricula can be framed to address specific agendas and concerns. The content and delivery of the curriculum is examined as is the development of the key graduate attributes that typify this new engineering discipline. This case study provides a curriculum response to the specific needs of new product development which were identified in Chapter One and which will be discussed in detail in later chapters. The Swinburne PDE program featured in this case study is typical of the discipline, with similar attributes and curriculum inclusions as evident in the findings of the curriculum benchmarking survey. It provides an opportunity to discuss and reflect on various aspects of the discipline including the benefits and challenges of delivering new engineering educational models.

Chapter Three examines aspects of the Product Design Engineering curricula that respond to industry expectations for these engineers in the new product development. In particular it discusses the fostering of creativity though the inclusion of design pedagogy, and the development of key skills such as drawing.

Case Study 1: Examination of the Swinburne PDE Curriculum

Introduction

This case study examines a typical Product Design Engineering curriculum, in this instance the program from Swinburne University of Technology, in Melbourne.
It aims to provide an insight into the new engineering discipline of Product Design Engineering through a close examination of an individual program; its curriculum and delivery, industry engagement and industry relevance, external measures of success, career pathways and the challenges of inter-disciplinary education.

Program structure

The Product Design Engineering curriculum at Swinburne "with its design-enhanced accredited engineering structure offers a unique and increasingly global response to the need for engineers to demonstrate designerly thinking in addressing product design problems" (de Vere, Melles et al. 2009, p. 41).

The curriculum of the four year (32 subject) undergraduate (BEng.) honours course (as outlined in Figure Cs1.1) comprises:

- 50 percent engineering content (16 specific engineering subjects mostly shared with the mechanical engineering program),
- 40 percent design subjects (12 subjects mostly unique to the PDE program, led by the design faculty), and
- a minor stream of study (4 elective subjects).

Through electives, the program offers students the possibility of specialising in manufacturing engineering, biomedical engineering or electronic engineering, or taking design units including design management, brand strategy and sustainability.

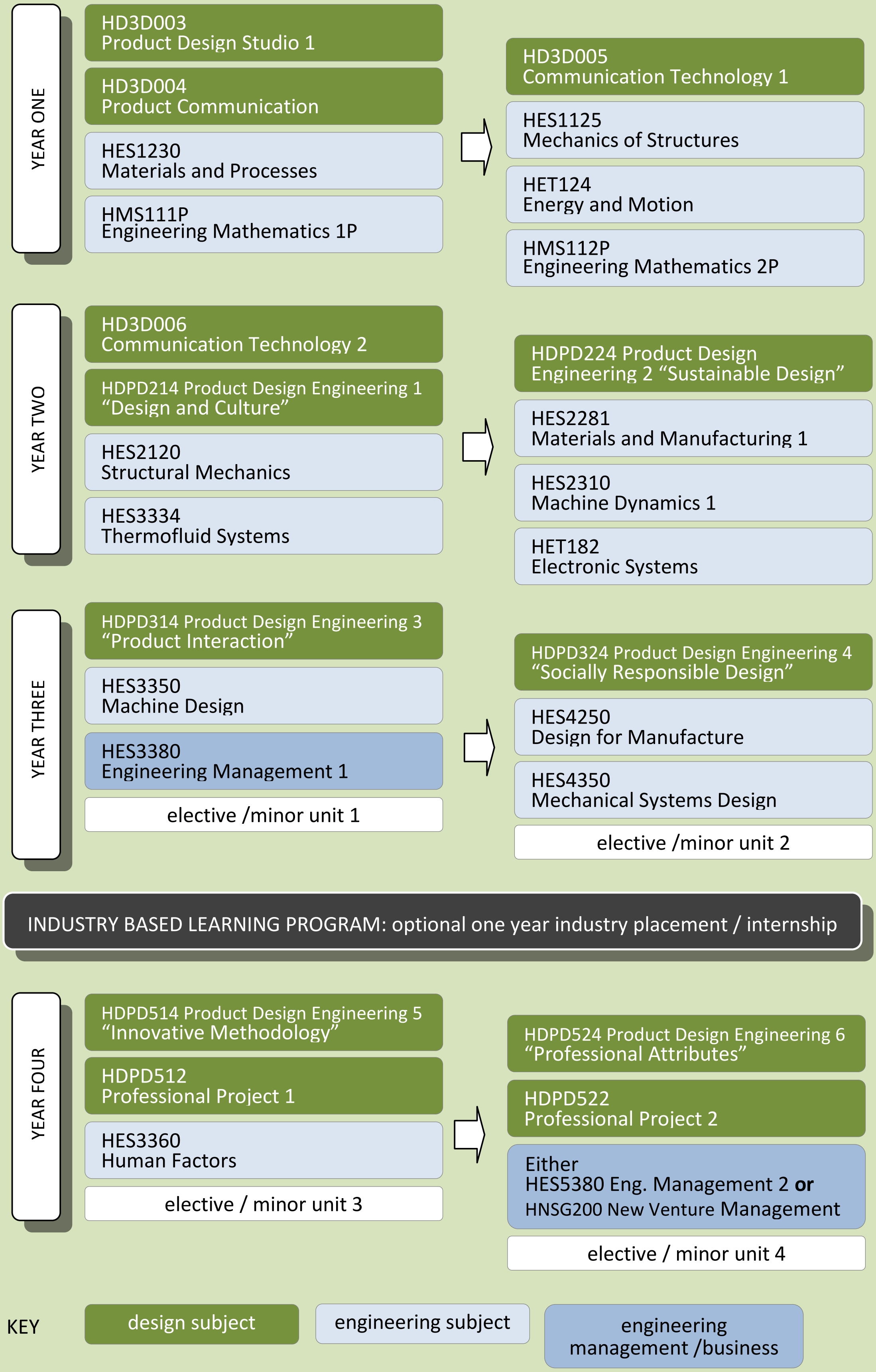

Figure Cs1.1: The Swinburne PDE course structure – a typical example of Product Design Engineering integration of design content into the engineering curriculum (image source Ian de Vere)

Curriculum development and delivery is facilitated by collaboration and cohesion between the Engineering and Design faculties. The Swinburne PDE course, which is unique in Australia, has benefited from a clearly articulated vision, and commitment and zeal from the coordinators and lecturing staff from both faculties. The course is well supported by current students and the alumni, many of whom contribute to the program through sessional teaching and industry partnerships.

The design projects develop creative skills, and support and apply engineering theory to product outcomes. Engagement with industry and community is frequent and includes externally-led projects from the manufacturing and design sectors or real-world scenarios provided by humanitarian agencies. After the industry-based learning internship year, the self-initiated final year project expects students to collaborate closely with industry partners on unprecedented social need projects.

Engineering subjects are taken mostly directly from the mechanical engineering course, however to meet Engineers Australia (EA) course accrediatation requirements, design subjects are usually unique to the PDE program, (with the exception of early skill-based subjects which are shared with industrial design). The unique design content ensures that the course meets minimum engineering content requirements, and addresses the EA stipulation that all design subjects include engineering content and the application of engineering theory to design outcomes.
This ensures sufficient engineering rigour for full international recognition as engineers; an important criteria that sets the BEng PDE graduates apart from the graduates of other multi-disciplinary courses such as Industrial Design Engineering.

The PDE curriculum (refer to Figure Cs1.1), offers sixteen engineering subjects out of a course total of 32. PDE students therefore undertake less than 60 percent of the engineering theory content of the mechanical engineering course which requires students to complete 28 engineering subjects. This is due to the need to provide sufficient design content, and electives. However it is possible for PDE students to recapture some of the lost engineering depth, by choosing an elective minor of four engineering subjects.

The PDEs complete most of the engineering foundation units (with the exception of the two Robotics and Mechatronics units) but lack depth in Mathematics as they are required to complete only the first two, of four maths units.

It is in the technical studies units where the PDE students lose depth in engineering theory. The four subject block of Thermodynamics 1 and 2 and Fluid Dynamics 1 and 2 is replaced for PDE by the single unit 'Thermofluid Systems' which introduces the fundamental principles of these engineering areas, but does not provide the full depth of knowledge. The PDE students also miss out on the second Machine Dynamics and Solid Mechanics units, but these are replaced by Design for Manufacture and Human Factors (which are mechanical engineering electives).

None of the missing content is particularly necessary for engineers engaged in product design, and PDE graduates are still certified as fully accredited engineers, but the comparative lack of depth in engineering can lead to uncertainty when faced with complex mathematical calculations and engineering analysis.

Program delivery

The PDE program is delivered by experienced design and engineering academics, supported by a large number of sessional staff, all current practitioners in product design and manufacturing environments.

Whilst the program results from collaboration by two faculties, it is rare that staff from both faculties teach together in a common subject. This is due mostly to administration reasons, rather than any lack of synergy between design and engineering staff, as the faculties are located on different campuses.

Whilst the accrediting body (Engineers Australia) would like to see more engineering faculty staff teaching into design subjects, there are few engineering academics available on staff that have the necessary industry experience in product design to contribute significantly to the teaching of the design curriculum.

Consequently, the design subjects often utilise the in-class services of an experienced engineering practitioner for technical support, the application of engineering theory and to ensure industry relevance. These sessional staff are typically PDE graduates (with a minimum of five years industry experience) who are well versed in the product design process.

Early in the program, design projects are created by lecturers to meet specific learning criteria and to support the engineering theory. As the course progresses, engagement with industry and community partners develops. In the third year students undertake industry-led technical projects (e.g. heat pump designs) or humanitarian projects based on scenarios provided by aid agencies (such as World Vision Australia and Engineers Without Borders). After the 'Industry Based Learning' internship year, the final year project expects the students to collaborate closely with industry partners, who have a pro-active role in defining the project, then evaluating and assessing the designs against real-world criteria.

At Swinburne, the PDE students benefit from access to the full teaching, workshop and laboratory resources of both the design and engineering faculties in addition to student facilities available across the two campuses. Students have dedicated design studio spaces and rapid prototyping facilities, which have facilitated the development of a 'studio culture' and a strong student community. Students have access to a range of 3D-CAD and product visualisation software (e.g. 3DS Max, V-Ray) and 3D visualisation facilities, CNC equipment and additive manufacturing technologies for rapid prototyping.

Although the program includes only a general grounding in electronic systems as part of the mechanical engineering syllabus, students are encouraged to seek the input of electronic engineering academics and to engage closely with electronic industry partners in the development of their products. The PDE program realises the importance of digital systems to the success of many products, and while not teaching electronic system design in any great depth, concentrates on the design integration of these systems. This includes product interaction design and interface design, including schematic planning for Graphic User Interface (GUI) systems.

Interdisciplinary Learning

Interdisciplinary learning is an ideal pedagogical model as students make cross-curricula connections and unite skills and knowledge from numerous sources and experiences. Students learn to utilise diverse and contradictory positions, understand issues contextually and learn to apply their abilities to practical outcomes in multiple environments. Resultantly, interdisciplinary learning creates knowledge that is more holistic than knowledge developed in discipline-specific studies. Whilst arguably less effective for building 'depth' of knowledge, it emphasises higher-order thinking (e.g., analysing, applying, generalising) and guides learners beyond simpler forms of knowledge acquisition, to a deeper assimilation of cross-disciplinary concepts (Ivanitskaya, Clark et al. 2002).

In the Product Design Engineering curricula at Swinburne, the design and engineering subjects are delivered in a parallel manner with varying degree of cross-fertilisation or integration occurring both formally and informally. Design subjects utilise the in-class support of experienced Product Design Engineers. These practitioners offer engineering support, technical expertise and ensure that design units have sufficient engineering content to meet EA accreditation requirements.

Project outcomes require the application of engineering science in the context of a design problem. The product development 'approach' is unique and differs from industrial design in that products are often designed from the '*inside out'* – the product architecture is engineered before the product is designed, ensuring that engineering expertise is fully integrated into the design process.

The importance of the open-ended design project

Engineers are often engaged in pragmatic problem-solving, where cost-effective and 'known' solutions are developed through sequential convergence on a solution. However, many of the problems facing the twenty-first-century design engineer will be ill-defined and not amenable to the techniques of science and engineering (Cross 2006). These problems will require creativity and skills in problem-framing and problem-solving, and engineers will need specific training to develop divergent and flexible dichotomies, and the creative design skills to successfully resolve poorly defined problems (Wulf 2000).But whilst creative designing may be discussed in (engineering) product design texts, these considerations are subordinate to product specification and documentation processes (e.g. (Ullman 1992).

The PDE program aims to encourage a capacity for creative design and open problem-solving, and attracts divergent thinkers who have a natural instinct for creativity (Lewis 2004), who would normally gravitate towards design or the arts. Projects range in scope from small specialist or consumer products to larger scale infrastructure projects that may address humanitarian or social issues. These examples are indicative of a design philosophy that clearly integrates the dual discipline nature of Product Design Engineering; technically well resolved solutions that are user-focused, appropriately styled and innovative. High quality student outcomes result from four years of experience in open-ended problem solving through design project-based experiential learning.

The dual consideration of engineering and design is illustrated clearly in examples of student designs in Figures Cs1.2, Cs1.3 Cs1.4 and Cs1.5 (below). These student design examples demonstrate the opportunities created by design projects for students to apply engineering theory to practical product outcomes, whilst developing creative design skills. Evident in this final year work is maturity of design, a high level of technical and aesthetic resolution and a user-centred focus.

Figure Cs1.2: Landmine detection vehicle. A remote controlled self-levelling rugged terrain vehicle that uses gamma and metal detection systems to detect landmines without risk to personnel. (Image source: final year Product Design Engineering project)

Figure Cs1.3: Medical diagnostics device utilising microfluidics technology to detect HPV cervical cancer (Image source: final year Product Design Engineering project)

Figure Cs1.4: Hybrid mobility shopping aid for the elderly, it combines a walking frame with a user-sensitive shopping cart. (Image source: final year Product Design Engineering project)

Figure Cs1.5: Working with the Victorian Eco-Innovation Lab (VEIL) to examine new approaches to public transport – tram design project. (Image source: group project – final year students)

Traditional engineering pedagogy using theory-based learning has been criticised for not preparing students for the 'practice of engineering' (Dym, Agogino et al. 2005). However, the design subjects within the PDE curriculum utilise experiential learning methods which foster creativity and develop real-world problem solving ability. Project-based learning is integral to PDE student learning as it instils the tools of design practice early in the curricula, then allows significant opportunities for development of skills, knowledge and confidence.

It appears that engineering students require opportunities to apply their science through project-based learning, in addition to problem solving activities that do not provide a unique or tangible outcome for evaluation. The PDE curriculum reflects the understanding that project-based learning is constructive, participatory and the most effective way to educate creative engineers for in new product development.

Fostering Creativity through 'Designerly Ways'

Cropley (2000) found that a significant number of engineers are considered unsuitable for employment due to deficiencies in creativity and problem solving. However, the Product Design Engineering curriculum integrates aspects of design pedagogy, including sketching, divergent thinking, reflection-in-action, problem framing, and open-ended problem solving to instil and foster creativity.

Designerly ways

The PDE curriculum balances the techno-scientific approach of the engineer with the intuitive approach of the designer. Design projects allow for students to problem solve both by analysis (as is common in engineering) and by synthesis, the designers approach (Cross 2001). The 'designerly ways' user and solution focussed approach is an appropriate response to the demands of addressing poorly defined problems.

The role of sketching

The inclusion of design curricula in PDE enables perspective sketching and rendering to be integrated into the learning experience, from the first semester through to the final year, with a shift to CAD occurring only at the project stage of product definition and documentation. The importance of drawing, as both an essential industry skill and an instrument of creativity, is reflected throughout the PDE curriculum with the expectation that students will achieve a high level of creativity and design skills including sketching proficiency. This will be discussed in detail in Chapter 3, *Creativity and innovation*.

Social responsibility and sustainability

The Product Design Engineering curriculum at Swinburne, includes a sustainable design covenant that ensures students are taught skills and awareness, plus the tools to affect behavioural change and to lead reform in design practice and manufacturing. Equally importantly, students are taught to consider the needs and aspirations of those at the base of the pyramid (the other 90%); those who lack the basic elements that constitute a safe, healthy and equitable existence. It is here that product designers can make the greatest contribution to the societal improvement.

Social responsibility and sustainability are key themes throughout the curricula. In second year students learn sustainable design theory and practice and develop low impact products, whilst in third year subjects students engage with humanitarian aid organisations to develop product and infrastructure solutions to the specific needs of disadvantaged communities. In the final year capstone projects, the students are required to develop projects that address social need, energy consumption, waste minimisation and disaster relief and use alternative or emerging technologies. The agendas of sustainable design and socially responsible design are critical for those engaged in new product development, and are discussed in detail in Chapter 4, *Ethical engineering.*

The student design outcomes below (in Figures Cs1.6 and Cs1.7) are indicative of socially responsible design projects at the third and fourth year level. The aerobic toilet was developed by students working collaboratively with a humanitarian aid agency following the Banda Ache tsunami disaster of 2004. This design utilises low cost materials and manufacturing processes and is guided by the need for simple user-product interaction and utilitarian values. The gravity powered dynamo lamp is an example of simple engineering principles being applied to overcome a lack of power infrastructure in remote African regions. Both products place the immediate needs of the user and aid agency supplier, over more commercial aesthetic values, but address the needs of the target community effectively.

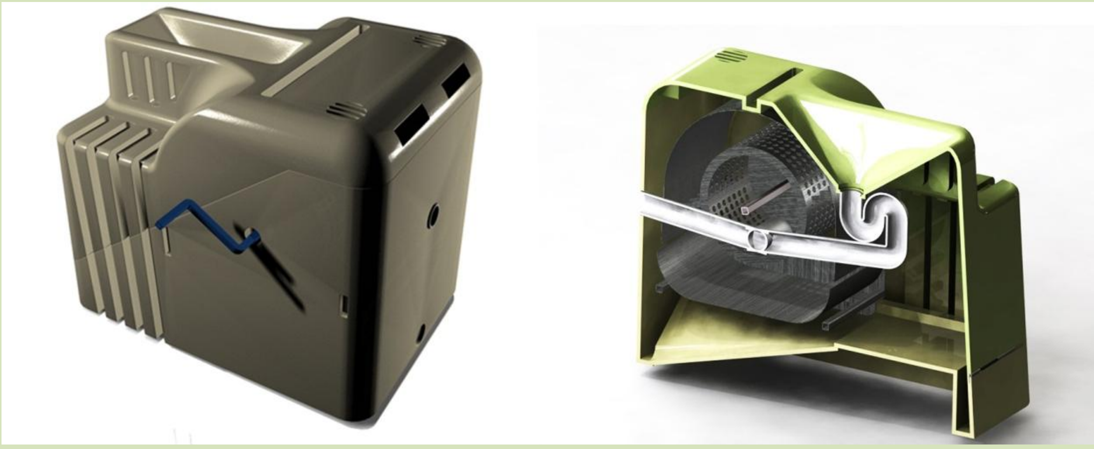

Figure Cs1.6: Socially responsible design (SRD); a hand powered portable aerobic toilet for use in disaster relief. (Image source: 3rd year PDE student design – group project)

Figure Cs1.7: Socially responsible design (SRD); a portable light powered by a dynamo which is driven by a weighted rope. (Image source: final year PDE student design)

Student demographic

Student satisfaction

Student and graduate satisfaction at Swinburne is high. The PDE students and graduates recognise that they are members of a unique professional community, possessing graduate attributes rarely found in industrial design or other engineering graduates. Initially some students struggle to deal with the multidisciplinary approach and cross cultural, cross-campus course delivery (with subjects being offered equally by both engineering and design faculties). Yet once the foundations of both disciplines are established, students quickly settle into an interdisciplinary methodology which is flexible and adaptable.

The Swinburne PDE course offers more discipline-specific design studios than many industrial design courses, making it a viable alternative to a pure design course for those students with an artistic flair, with the added benefit of a fully accredited engineering program. Whilst most students display specific aptitude and leaning towards one of either design or engineering, they are equally challenged in both fields and the integrated curriculum provides the engineering students atypical opportunities to apply engineering science to real problems.

It is a measure of the course's appeal and success that so many of the part-time sessional staff contributing to the teaching program are graduates of the course. These engineering design professionals with five to eight years industry experience, are strong advocates for the discipline, keen to help develop awareness of Product Design Engineering as a profession, within industry and the wider community.

The entrance requirements, whilst specifying the normal engineering entrance requirements of science and mathematics, also require an interview and folio review. This ensures that students have the capacity both for the technical demands and creative requirements of the course. In line with global PDE programs, the Swinburne course boasts high student retention rates, and is particularly successful in attracting female students; a problem for more traditional engineering curricula.

Female demographic

It was noted in the Chapter Two: *Examination of global PDE curricula* that Product Design Engineering appeals to a student demographic that is not usually enticed into engineering education, including young women. Engineers Australia in their 2008 review of Australian engineering education noted a female predilection for certain engineering subfields, but reported that overall "females studying engineering are significantly under-represented" (Engineers Australia 2008, p. 18).

The Swinburne PDE program has a significantly higher proportion of enrolling and graduating female students compared with other engineering disciplines. Over the last eight graduating years, female PDE graduates ratios have averaged close to 25 percent of yearly cohorts, comparing favourably to more established engineering disciplines at Swinburne, and to the Australian national engineering average. These figures compare favourably with Engineers Australia's Statistical Overview which reports that "the enrolment rate of women in undergraduate engineering courses has remained at 14 percent since the early 1990s, peaking in 2001 with 15.7 percent" (Engineers Australia 2009, p. 44).

Within Swinburne, Product Design Engineering has proved highly successful in the recruitment of female students when compared with Mechanical Engineering (2 percent females) and the Faculty of Engineering average, which at 10 percent is well below the national average (Swinburne RQF Report 2007).

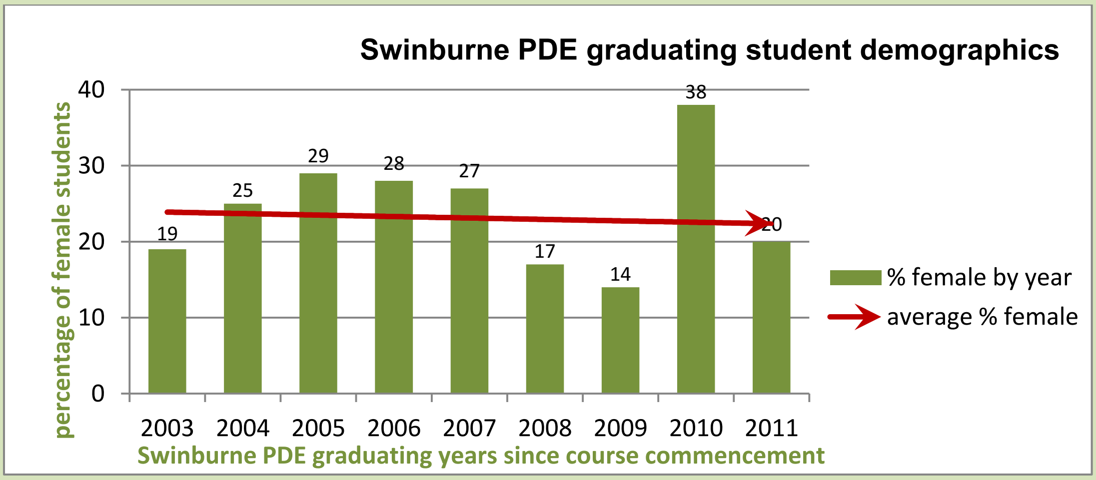

Figure Cs1.8: The PDE student demographic – female ratios since course commencement (data source: Swinburne graduation statistics)

These figures indicate that this new engineering curricula is successful in attracting student demographics that typically would not choose a mechanical engineering career, despite the fact that 60 percent of the PDE curriculum content is mechanical engineering. This has great potential to redress the gender balance in new product development teams.

Retention rates

Also consistent with global data are student retention rates (course completions) which in the PDE program are generally higher than all other engineering programs, particularly among female students. This suggests that the interdisciplinary balance of design and engineering curricula, the human-centred focus and the design project-based learning process, has sustainable appeal to the student demographic.

International recruitment

Whilst international student numbers are typically lower for PDE than for more well-established educational programs such as mechanical engineering or industrial design, the course has successfully attracted students from Norway, Columbia, Japan, Malaysia, Scotland, the Netherlands, France, India, and China, who have all travelled significant distances to Australia to study Product Design Engineering.

Industry relevance

Industry engagement

Collaboration with industry is an intrinsic element of the Swinburne PDE program with industry engagement occurring at multiple program levels, including:

- industry involvement in teaching activities/program delivery,
- industry-led projects (where activities and outcomes are externally directed),
- industry based learning through student internships,
- industry collaboration/partnerships in final year capstone projects,
- external workshops and competitions, and through the
- industry course advisory committee

During their studies, students experience teaching and mentoring by designers and engineers engaged in new product development, have the opportunity to spend up to twelve months on university organised placements (paid internships) and respond to briefs directed by technology research and work on actual industry projects.

Students complete a capstone project during the final year of their degree. The project work spans both semesters and is generally a humanitarian or user-centred product that students design in collaboration with industry partners. This research and design project is the culmination of the learning journey and is discussed in detail in Chapter 5, *Collaboration with industry*, a case study of the final year PDE capstone project at Swinburne.

Program successes

Swinburne Product Design Engineering students have been successful in many design competitions both in Australia and internationally. Whilst the curriculum is not directed by the requirements of competitions, it is seen as valuable for students to be able to measure themselves against other design or engineering students. It is also critical for those about to graduate to build folio content and an individual profile that is independent of their student project work. Whilst some design projects align with specific competitions, in most instances students are encouraged to find and enter competitions on their own initiative. In recent years the PDE students have won major competitions either individually or in teams, some of which are listed below:

- 2012 International Design Awards (IDA) – Gold Award,
- 2012 EDF Sustainable Design Challenge,
- VACC Target 2020 competition for concept car design,
- ALSTON Light Rail 2020 competition for tram design,
- 2006 Dyson Student Design Award, and
- 2006 and 2008 Reece Bathroom Innovation Awards.

Figure Cs1.9: Gold Award winning entry, 2012 International Design Awards.
Ishke water purifying dispensing system (Image source: winner Jesse Leeworthy)

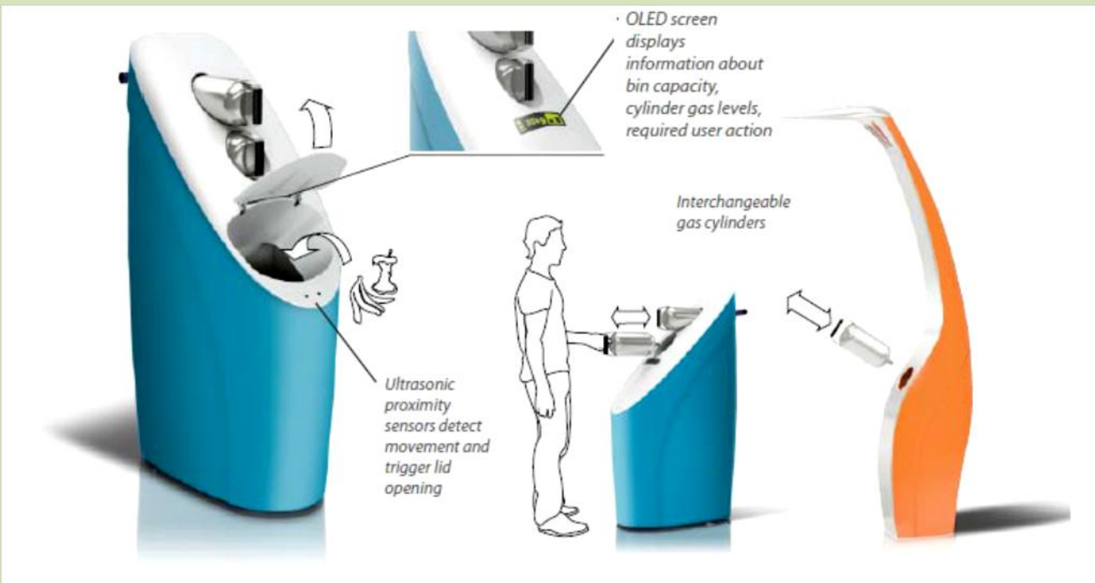

Figure Cs1.10: 2012 EDF Sustainable Design Challenge winner
Gastrom biogas generator converts restaurant food scraps to methane through anaerobic digestion.
(Image source: final year PDE students)

Career pathways

Career pathways for PDE graduates continue to be both encouraging and perplexing. It is difficult to define the exact categorisation of this new discipline by industry, as individual employers utilise them in different environments and with diverse roles and responsibilities, even within the same organisation. It is common to find a PDE graduate in a manufacturing engineering position liaising with a former classmate who is engaged in front-end product design. Whilst this can be partly attributed to individual strengths, equally it could be attributed to the graduate's adaptability and flexibility, and their multidisciplinary skill sets. The curriculum is validated by evidence of PDE graduates working across all areas of the design, engineering and manufacturing sectors, and their rapid progression into leadership and management.

Students have established new engineering roles in industry, including in industrial design consultancies with product engineering and front-end design roles, in manufacturing as production engineers, and as part of research and development teams in design and engineering design roles. In the student project example below the student utilised the design outcome form his final year capstone project to secure employment in a bio-medical research and design facility.

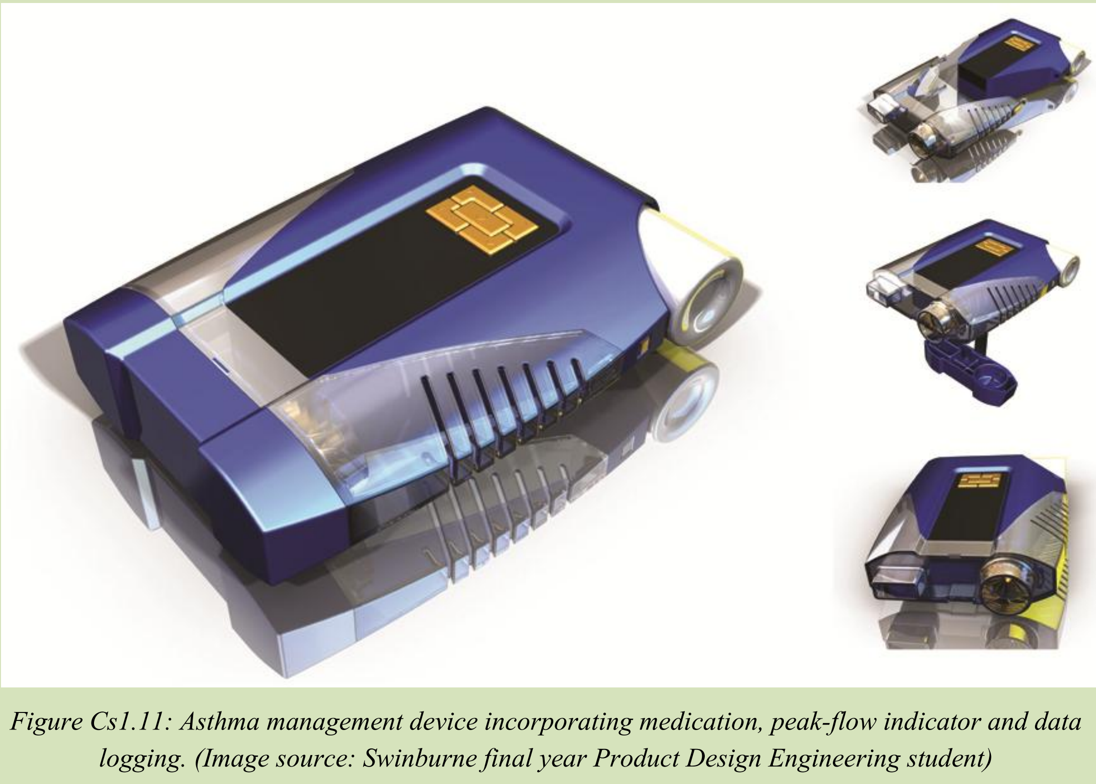

Figure Cs1.11: Asthma management device incorporating medication, peak-flow indicator and data logging. (Image source: Swinburne final year Product Design Engineering student)

Several early graduates (now experienced practitioners) have formed their own product development consultancies, specialising in engineering design and analysis, product design, development and manufacturing management.

Employers in the transportation sector include Ford Australia, General Motors Holden, Toyota, Bombardier Transport, Paccar/Kenworth and Alstom Trams.
In the design industry, many leading consultancies benefit from the unique and diverse skills of the product design engineer.

Graduates have been enthusiastically received by industry with the course maintaining 100% graduate employment statistics for the five years preceding the global financial collapse of 2008, and the 2010 and 2011graduating year shows signs that the demand for PDE graduates is returning to former levels.

Impact on industry

Product design and development environments are often hampered by inflexibility, lack of understanding and professional rivalries, but are enhanced by innovative engineers such as the Product Design Engineers. Their interdisciplinary approach negates professional rivalries, connects disparate disciplines, and develops new relationships based on trust and respect.

The ability of graduates to work across disciplines has led to far greater employment opportunities than for either industrial design or mechanical engineers in the same workplaces. Already well established in the engineering and manufacturing sectors, PDE graduates are now impacting on industrial design roles.

Swinburne University of Technology PDE graduates have made a significant impact in local product design and development. From observation of, and discussions with, leading industrial design consultancies in Melbourne, it is apparent that the Product Design Engineering model is leading a trend in product design and development team constitution, with these interdisciplinary professionals occupying positions typically held by industrial designers and mechanical engineers.

All of the major design consultancies, in addition to major manufacturers, are employing PDE graduates to facilitate the provision of extended services to their clients and engage in brand building, global manufacturing and sustainable design solutions. Swinburne Product Design Engineering graduates represent approximately 20-30 percent of the design staff in the leading Melbourne product design consultancies, the balance being mostly industrial designers, with some mechanical engineers. This is a significant achievement for a single course that has only ten years of graduates and still developing public awareness as a distinct engineering discipline.

Employers have revealed that they are more inclined to employ a Product Design Engineer for a traditional ID role, on the basis of their greater technical ability. It is felt that Product Design Engineers 'reflect the rigour of industrial design graduates of previous generations', however they have broader capabilities, are more industry ready and can make a valuable contribution immediately upon employment. By contrast employers reveal that most ID graduates lack technical knowledge and an understanding of professional practice, as a result of an education process that is less rigorous and more generic in nature. In consultancies whose activities were defined as approximately 20 percent front end creative, 60 percent detail design and 20 percent project management, the PDEs are viewed as a better investment, with several industry employers declaring that they prefer Product Design Engineers when hiring graduates or junior staff (refer to Chapter 8, *Industry relevance*).

Employers state that the Product Design Engineers are better suited for new product development than mechanical engineers. With superior design skills they have been found to be more creative, with stronger understanding of user requirements and the ability to communicate and contribute across disciplines throughout the organisation.

Challenges of new engineering educational models

Product Design Engineering, with its design-enhanced accredited engineering structure, offers a response to the need for engineers to demonstrate 'designerly' thinking in addressing product design problems. It occupies a unique position, juxtaposed between the 'adaptive' design space of the engineer and the 'new' design space of the industrial designer; however as is common with multidisciplinary education, it is not without its cultural and pedagogical issues.

The challenge for engineering staff has been to develop a greater appreciation of the importance of design in product design and development. Similarly, design staff have to better understand the engineering discourse and approach to design. Course development is currently focussed on improvements in the teaching of engineering science to ensure the successful integration of the design and engineering disciplines.

Lecturers face a variety of challenges including managing student expectations and workloads across two faculties, and must ensure that students are supported and cognisant of the connection between the science of engineering and its articulation through the design projects. In this regard, almost all of the design subjects are written exclusively for the PDE course, to ensures that the course meets accreditation requirements for engineering content and rigour across all areas of study. These subjects which apply engineering in a design-project context develop far greater synergies between the disciplines, than is found in double-degree courses.

It is not ideal that the curriculum comprises design subjects which are unique to the PDE program, but that most of the engineering content is shared from a common pool of subjects undertaken by all mechanical engineering students. This is a restraint placed upon the curriculum as a result of the course accreditation process. Engineers Australia accreditation panels not familiar with the Product Design Engineering discipline tend to be wary of subjects that differ from conventional engineering curricula, and which appear to be less rigorous in engineering science. Consequently it is expedient to include previously accredited engineering content from other engineering disciplines, in order to demonstrate that the PDE program has sufficient engineering rigour.

Discussion

It can be difficult to establish a new discipline in the design and manufacturing sectors where roles and attitudes can be well entrenched. However the Swinburne Product Design Engineering program has been successful in gaining a foothold into Australian industry, despite the difficulties associated with sole curriculum delivery. Whilst the graduate industry uptake within Australia would be enhanced if more institutions were to offer the discipline, the long standing industry based learning program has allowed students to showcase their abilities.

The Swinburne Product Design Engineering program has succeeded in establishing a new engineering discipline in Melbourne and has demonstrated the effectiveness of multidisciplinary engineering education, particularly for specific employment environments, such as new product development.

The success of this program has resulted in another Melbourne university offering their version of Product Design Engineering, B.Eng in Electronic Product Design. This new program, to be offered for the first time in 2013, combines industrial design and electronic engineering curricula and is consequently more focussed towards one particular industry and narrower in scope than the Swinburne program. It is one of the strengths of the Swinburne Product Design Engineering curriculum that its graduates have proven employable in a wide range of design and manufacturing environments.

Chapter three: fostering creativity and emphasising sketching

3 .1 Overview

Chapter One identified creativity and design skills (including sketching) as essential graduate attributes for engineers engaged in new product development. In Chapter Two, the global curriculum benchmarking survey found that 90 percent of global Product Design Engineering program leaders identified creativity as a key student competency and viewed drawing ability as "absolutely essential" and "a fundamental link to creativity."

This chapter draws from three peer-reviewed conference papers which dealt with a curriculum that develops creative engineers, and examines the development of a drawing culture amongst engineering students.

The first paper,

> de Vere, I. (2009) Developing creative engineers: a design approach to engineering education. *Creating a Better World, the 11th International Conference on Engineering and Product Design Education (E&PDE),* University of Brighton, UK.

examined the 'need' to foster creativity in engineering education and presented Product Design Engineering as a curricula with a strong focus on the development of design skills, sketching ability, problem framing and innovative practice.

The integration of 'designerly ways' into engineering curricula responds directly to the call by engineering regulatory accreditation organisations, and leading engineering academics, (refer Chapter 1) to generate engineers who are not only competent technicians, but also experienced engineering design practitioners, with a creative, flexible and adaptive approach and a design philosophy that seeks innovative solutions.

In addition, an examination of drawing curricula draws from the following papers:

> de Vere, I., Melles, G., Kapoor, A. (2012) SketchFest: Emphasising sketching skills in engineering learning. *The 14th International Conference on Engineering and Product Design Education (E&PDE2012)*, Antwerp, Belgium

de Vere, I., Melles, G., Kapoor, A. (2011) Developing a Drawing Culture: New Directions in Engineering Education, *International Conference on Engineering Design (ICED11)*, Technical University of Denmark, Copenhagen, Denmark.

[Note: This paper received the ICED11 Reviewers' Favourite Award in recognition of the paper being ranked in the top 5% of papers based on reviewers' scores.]

These papers examined the role of sketching in product design and development, detailing the differing roles of sketching; ideation, technical resolution, communication, form giving and persuasive drawing, and emphasising the need for creative exploration and critical reflection. This chapter combines and expands these papers, providing a detailed examination of the Product Design Engineering curricula fostering creativity though integration of design pedagogy.

At the end of this chapter, Case Study 2, *Developing a Sketching Curriculum* investigates teaching initiatives within the Swinburne PDE program to integrate drawing into the engineering curricula, and enhance student creativity.

3.2 Introduction

"Universities must show how graduates could achieve the ability to be creative and innovative." (Engineering Council 1997, p. 4)

"We must foster creativity in design."
(Accreditation Board for Engineering and Technology 1998)

Creativity has been identified as a key graduate attribute for engineers engaged in new product development and a critical expectation of engineering regulatory and course accreditation organisations (refer Chapter One, Section 1.7). It is implicit that creativity is integral to design innovation, and that design and the fostering of creativity should be the cornerstone of engineering pedagogy. "The purpose of engineering education is to graduate engineers who can design" (Dym et al. 2005, p. 103).

In the United Kingdom, the SARTOR (Standards and Routes to Registration) accreditation document by the Engineering Council requires universities to show how graduates could achieve the ability to be 'creative and innovative' (Engineering Council 1997). This position is comparable with US engineering regulatory organisations. ABET has emphasised its desire to foster 'creativity in design' (Accreditation Board for Engineering and Technology 1998), sentiments echoed by Beder (1997) who has called for a cultural change through which students will develop 'innovation and creativity' and Akay (2003) who advocates the need for a 'renaissance' engineer who is a creative thinker.

As creativity is central to innovative problem solving, it should be integral to the education of engineering designers. To be creative, engineers must pursue uniqueness, accept unusual ideas, tolerate the unconventional and seek unexpected implications. Without a focus on design activities and creativity, graduates will be competent technically, but not capable of engineering innovation.

Despite the fact that design is fundamental to engineering practice, and therefore should be a motivating factor in engineering learning, there is little evidence that students have sufficient opportunity to develop design aptitude or an adaptive and creative approach. Pappas, in his examination of creative problem solving in engineering, notes that although engineering is a creative endeavour, “many engineering colleges fail to address this, and end up training engineers for technological task completion” (Pappas 2002, p. 1). Accordingly, it is common for engineering graduates to lack both aptitude in the creative resolution of ill-defined problems, and experience in real world practice.

By contrast, industrial design pedagogy, although lacking the technical depth, scientific knowledge and analytical skills of engineering curricula, fosters creativity by developing and nurturing problem-solving skills and provides regular opportunities for students to refine these skills through experiential design project-based learning. Creative activities such as ‘reflection in action’, problem framing, divergent thinking, and open-ended problem-solving are integral to the designer’s education.

There appears to be a need for engineering curricula to utilise the creativity tools common to design pedagogy. The development of new engineering curricula, such as Product Design Engineering, is one such approach; albeit one that directly addresses the needs of a specific industry segment (e.g. new product development). However some revision of the wider mechanical engineering curricula could also be warranted, in particular reform of the theory-based curricula model as to emphasise experiential learning through creative design activity. “University has to foster creativity” (Eekels 1987, p. 262)

It is important that engineering faculties provide sufficient curriculum opportunities for students to develop design skills, and creative methodology. This can be achieved though targeted learning within an engineering educational context. In this regard, engineering education can benefit from the integration of some aspects of design pedagogy. Product Design Engineering, through integration of design and engineering curricula, has produced graduates who balance a scientific and analytical approach with creative design to solve ‘wicked’ design problems.

3.3 The Creative Engineer

"As educators, we are responsible for stimulating creative thinking among our students... Our ultimate goal is to require original creative work as part of every engineering course" (Richards 1998, p. 1038)

3.3.1 The need for creative engineers

Some still question the importance of creativity in engineering education. Engineers are normally engaged in pragmatic problem solving, where simple, cost effective 'known' solutions are preferable over 'creative' solutions that require extensive investigation and resolution. The design and engineering disciplines are purportedly dissimilar, "engineering is a scientific and analytic profession; design is constructive, a pattern of behaviour employed in inventing things of value which do not yet exist" (Gregory 1966).

Nevertheless we are educating in a rapidly changing environment and must anticipate industry expectations and the emerging responsibilities of the new design engineer.
In a uncertain economic environment with diminishing resources, the onset of climate change and the need for sustainable design, a new engineer is required; one with a design philosophy that seeks unexpected and innovative solutions through applied creativity. Creativity has been defined as an imaginative activity fashioned so as to produce outcomes that are purposeful, original and of value (Robinson 1999), and as such is fundamentally important in engineering practice as it allows insight outside traditional engineering boundaries (Ghosh 1993) and allows engineering problems to be approached in original ways (Raskin 2003). "Creativity helps you consider multiple angles instead of just one, and it helps create bridges between different fields of knowledge, and between innovation and the tried-and-true" (Stouffer et al. 2004, p. 7).

However a fundamental change is required to achieve this. Engineers must be taught not to be sceptical of design and creativity, but instead to welcome the unexpected, and be confident working outside the comfort of science and structured processes.

3.3.2 Defining creativity in an engineering context

Creativity involves having unusual ideas, tolerating the unconventional and seeing unexpected implications (Cropley et al. 2000). This can be rather challenging for engineering students who are more comfortable working within defined parameters and tackling constrained, rather than open-ended, problems and who typically have a tendency to fixate on prior solutions. "Students must be aware that instruction in creative thinking will not provide the certainty offered them in most engineering tasks. Creative thinking is a more ambiguous endeavour than most engineers are used to or skilled in...there are no right answers" (Pappas 2002, p. 3).

Fry (2006) notes that traditional engineering assignments tend to be left brained and highly defined with specific steps and predefined correct answers. Such curricula do not encourage the development of creative thinking which requires "a non-linear, unstructured and flexible approach to solving problems and generating ideas." (Pappas 2002, p. 3)

Student acceptance and willingness to engage in creativity exercises can be determined by definition. By defining creativity as an 'approach' involving flexibility, fluency, novelty and definition (Fry 2006), rather than something resulting from 'ex nihilo' (out of nothing), the inherent uncertainty of creativity is less intimidating for engineering students.

It is essential that student engineers are comfortable and confident with the creative process. This can only be achieved through extensive experiential learning with creative methods in the engineering design process; making the 'strange' familiar (Stouffer et al. 2004).

Creativity, in the context of engineering design, should be seen as leading to innovative problem solving and must be developed and nurtured at all stages of the learning process. Students must be challenged to move beyond the technical aspects of the problem, and accept creativity as "a desirable mindset and attribute of engineers." (Stouffer et al. 2004, p. 10)

3.3.3 Engineering languages – the place of creative design in the curriculum

"Creativity is the essence of engineering. Yet creativity is neither explicitly taught nor promoted in the engineering curriculum. " (Santamarina 2002, p. 99)

Engineers Australia, the regulatory organisation responsible for course accreditation, states that a new engineering focus is required. Its National Panel on Design released a position paper in 2008 stating "design is a primary function of the engineering profession," and "engineering education should encourage an applications-oriented framework to teaching engineering science material and a greater emphasis on project work of a design nature" (Engineers Australia 2008, pp. 3-4).

Although recommended by engineering organisations and expected by industry, the development of design skills and creativity is not always evident in engineering curricula, due in part to the 'science' expectations of accreditation organisations. There is an 'educational justification for design' as a means to develop cognitive skills and real-world problem solving abilities (Fox 1981; Cross 2000). To achieve this, design needs to move from the periphery to a central role in engineering education.

3.3.4 Wicked problems

It is apparent that many of the problems facing the 21st century design engineer will be ill-defined problems, design problems that are not amenable to the techniques of science and engineering (Cross 2006). These 'wicked' problems (Rittel et al. 1973) will require a co-evolution of problem framing and solving, divergent and flexible dichotomies, creativity and a lack of fixation on prior solutions. Hence a new engineering approach is required. The new engineer should add not only functionality, but also respond to new societal challenges and lead necessary change.

To address ill-defined problems, engineers must be confident seeking unexpected solutions, operating outside established fields of expertise, using intuition in addition to mathematics, and pursuing innovation. This can be achieved through open-ended design problems which "force students to think creatively and ultimately foster in them an appreciation for developing creative solutions" (Ghosh 1993, p. 118)

3.4 Curriculum for creativity

The Product Design Engineering curriculum aims to develop creativity through the inclusion of ‘designerly ways’ (Cross 2001) into a mechanical engineering curriculum. Whereas a mechanical engineering curriculum would not typically involve extensive design projects, a design-led pedagogy affords students the opportunity for practical application of engineering science to address a problem through the design of a product outcome.

Creativity is developed throughout the Product Design Engineering course during the design projects. The studio-based learning facilitates the acquisition of design skills such as sketching, encourages innovation through intuition and divergent thinking, and develops open-ended problem framing and solving abilities. This experiential learning model moves beyond problem-based learning into areas where previous engineering science learning can not only be applied, but questioned and pushed into new areas of application.

The Dyson air multiplier bladeless fan (Figure 3.1) is an example of product design pushing engineering science (fluid dynamics, inducement and entrainment) to create an innovative user-centred solution. It is hard to imagine this product originating from an industrial designer, as the science is too complex without an engineering education. It represents highly creative engineering design, taking known properties of physics and applying them in an unprecedented but user-centred manner. It is therefore not surprising that the Dyson New Product Innovation office employs a significant number of PDE graduates (from Brunel, Swinburne and Strathclyde etc).

This image is unable to be reproduced online.
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Figure 3.1 Dyson air multiplier bladeless fan (image source Dyson website)

3.4.1 Developing creativity

Early approaches to fostering creativity concentrated on the training of specific skills (e.g. Osborn's brainstorming). However Cropley and Cropley (1998) argues that this ignores the non-cognitive aspects of creativity such as motivation and self-confidence and (Feldhusen et al. 1995) concluded that student creativity can be enhanced by teaching them to seek new ideas, recognise novel approaches and judge the effectiveness of novel solutions.

Engineering programs need to create positive attitudes towards creativity, motivate students to be creative and innovative, encourage student confidence in their creative potential and reduce anxiety about unexpected solutions in problem solving processes. (Cropley et al. 1998) It is insufficient to engage engineering students in problem-based learning exercises which prove only their knowledge of the 'science'. To develop knowledge into aptitude, students require experience.

Experience in the 'practice of engineering' should be obtained through experiential learning processes that apply engineering theory to scenarios requiring design resolution. Rigorous challenges requiring creative design solutions stimulate student interest, especially when engineering problems are addressed in unexpected ways, and science is creatively applied to tangible real world outcomes.

Figure 3.2: personal transportation vehicle concept
(image source: Aston University Product Design Engineering)

This concept vehicle (Figure 3.2) by a Product Design Engineering student at Aston University aims to address issues of resource depletion, urban congestion and greenhouse emissions through an innovative personal transport solution. In this example, creativity is expressed in the vehicle configuration, product-user interaction, and aesthetics. The highly conceptual design, whilst not necessarily realisable in the real world, is highly original and adds value to discussions regarding alternative transport and shows a potential employer the styling ability of the student. Whilst it is important to achieve technically possible project outcomes, it is also necessary to provide opportunities for unconstrained creative exploration to develop creative processes.

3.4.2 Sketching and creativity

The lack of emphasis on design in engineering education is evident by the minimal instruction in basic design ideation and articulation tools such as sketching. Without sketching ability, engineering students may struggle to uncover the unintended consequences, the surprises that keep the design exploration going in what Schon and Wiggins described as the 'reflective conversation with the situation' (Cross 2006). "It is in considering how these sketches help an idea take form, that gives a hint that drawing's role in engineering is more than just to archive a concept or to communicate with others" (Ullman et al. 1990, p. 263).

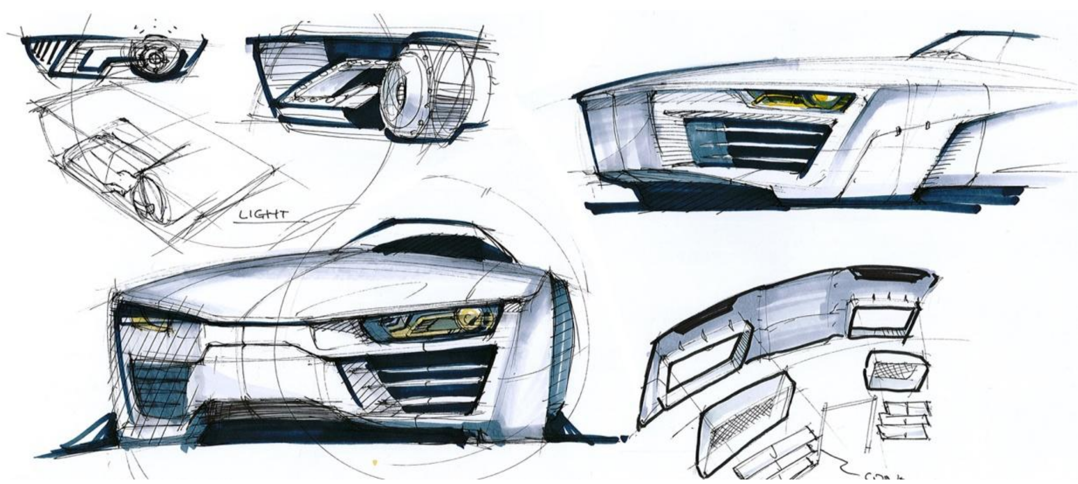

Figure 3.3: the creative sketching process (image source: Swinburne final year PDE student)

Sketching enables many different design and development functions, from initial aesthetic and functional exploration during the ideation stages, to technical resolution and detail design during the product embodiment stage and the communication of user-product interaction and assembly sequences.

Whilst 2D/3D CAD software is taught as part of engineering documentation studies, there is little evidence that sketching, the tool for thought articulation for problem framing, discussion and reflection, is valued in engineering education curricula. This is despite significant research that links sketching to creativity. Goldschmidt (2006) regards sketches as the 'imaginative universals' that trigger creativity, whilst Tate (2007, p. 61) suggests that the creative process "consists of cyclical loops of feeling, responding, evaluating, selecting and communicating," processes facilitated by the unstructured nature of sketching. It is therefore imperative that students are taught to sketch and to be less reliant on CAD, which can stifle creativity by imposing a rigid, structured methodology on the user, as discussed later in this chapter. As noted in a study of conceptual sketch activity at Glasgow School of Art, freehand sketches "are constrained only by the designer's imagination" (McGown et al. 1998, p. 441).

3.4.3 Learning from design pedagogy

"Industrial design students are asked to focus on novelty and originality, looking for new contexts and opportunities for innovation within a broad general framework. Engineering students predominately work to define a set of parameters and target values up front that would define a specific, successful solution within a narrow range. These two mindsets often clash as one seeks to broaden the scope of the problem, while the other is working to achieve closure" (Fry 2006, p. 4).

Designers use tacit, episodic, socio-cultural and experiential knowledge. They are comfortable with risk taking and ill-defined problems and utilise objective, subjective and emotional decision making processes (Woelfel et al. 2010). Product designers face uncertainty in the areas of context and emergent properties, in contrast to engineering designers who are typically occupied by technical issues and rely on adaptive design processes. It is common in the early design stages for the designer to know nothing of the goal, a situation where "notions of process, environment and implementation are neither precise nor verifiable" (Woelfel 2008).

As we acknowledge that “convergence is at the core of the engineering process, and divergence at the core of the industrial design process” (Fry 2006, p. 3), it becomes apparent that the path to creativity in engineering could benefit from the inclusion of design pedagogy, as has occurred within the PDE program. Engineering curricula must provide opportunities for students to not only apply their ‘science’ in a real world context, but to freely explore product possibilities unconstrained by limitations and restrictive parameters.

However “students must be aware that instruction in creative thinking will not provide the certainty offered them in most engineering tasks. Creative thinking is a more ambiguous endeavour than most engineers are used to or skilled in...there are no right answers” (Pappas 2002, p. 3). This is dangerous territory for the engineer who seeks to define solution through applications of mathematics and science, but critical for the development of engineers for roles in new product development.

3.4.4 Open ended problems

“The teaching of creativity has a limited impact if it is not immersed in problem solving exercises (Santamarina 2002, p. 12).

Experience of open-ended problems develops divergent and flexible dichotomies, problem framing abilities, a reflective approach and the skills to successfully resolve poorly defined problems (Wulf 2000). These are the tools that lead to creativity and subsequently, product innovation.

As many of the problems of 21st century engineering practice will be poorly defined, graduates will require a creative, divergent and adaptable approach, co-evolution of problem framing and solving, and less fixation on prior (or known) solutions. “To be adequately prepared for the challenges they will face throughout their careers graduates must be innovative, adaptable and creative designers; yet many are considered by industry to be ill-prepared for the application of engineering knowledge to real world problem solving and product outcomes” (de Vere et al. 2010, p 292).

To facilitate opportunities for student exploration, experimentation, and failure, as part of the learning process, design outcomes should not predefined by the project brief, instead students should be challenged with open-ended problems that develop abilities in problem framing and divergent thinking and foster creativity. To produce creative design outcomes, engineering students must learn to define the problem in both divergent and convergent modes and be flexible, fluent and original in their approach.

In the following example (Figure 3.4) students were presented with a real world scenario; the difficulties by those in remote communities with regard to the sourcing and transportation of clean drinking water. Projects such as these are not prescriptive, nor are outcomes or functional parameters pre-determined. The onus was on the students to understand the scenario, frame the problem and then respond with a well considered and appropriate design solution. This solution addresses different user scenarios including rolling across difficult terrain and floating across flooded landscapes, utilising an innovative 'captured ball' configuration that enables easy manoeuvrability.

Figure 3.4: Student outcome from open-ended problem solving exercise – water transportation across rugged terrain and flooded landscapes for communities who live displaced from water source. (image source: 3D-CAD image generated by final year Product Design Engineering student)

As part of this research, comparative evaluations were conducted by the author (and colleagues) at Swinburne University of Technology to evaluate and compare the design skills and problem solving ability of final year Product Design Engineering and mechanical engineering students. These comparative projects (refer Chapter Six) have revealed that the PDE students, who are familiar with 'designerly ways', are more confident and proficient with open-ended problems. However students from other engineering disciplines struggled to define and then resolve problems, without material or functional constraints to guide the project direction.

It appears that experience in the framing and resolution of ill-defined (or 'wicked' problems), is facilitated by an environment that:

- appreciates unexpected solutions,
- encourages experimentation and
- tolerates failure.

Resultantly, the Product Design Engineering students were ideationally fluent, confident with problem framing, and motivated to seek uniqueness and innovation. The comparison also included a constrained and more technical project in which the PDE students also excelled due to a more creative and flexible approach to the design process, and more experience applying engineering theory to design problems. This comparative evaluation is described in depth in the following published conference paper which is incorporated into Chapter 6, *Evaluating design and problem solving ability*.

> de Vere, I., Kuys, B.. Melles,G.(2010) A Comparative Evaluation of Aptitude in Problem Solving in Engineering Education. *When Design Education and Design Research Meet - the 12th International Conference on Engineering and Product Design Education, (E&PDE),* Norwegian University of Science and Technology, Trondheim, Norway

3.4.5 Project-based learning using the design project

Creative engineers are described as those who are driven to seek uniqueness and unexpected implications, develop unusual ideas and tolerate the unconventional (Cropley et al. 2000). These are common themes in design education, but rarely developed through engineering curricula.

Engineering pedagogy is typically a theory-based science model that has been criticised for not adequately preparing students for the ‘practice of engineering’ (Dym et al. 2005). By contrast design pedagogy fosters creativity and develops problem solving ability skills through a ‘learning in action’ experiential process that provides opportunities for practice-based learning. Integral to design education is the design project which instils the design process, introduces key skills in design practice and communication (including sketching) early in the curricula and then allows significant opportunity for skills development and confidence building.

Similarly, it would be preferable if engineering curricula provided more opportunities (through design projects) for students to experience real world design and apply their science to produce design outcome that provide a tangible for evaluation and allow creativity and innovation to emerge. “Project-based learning is one of the most appropriate and effective means of teaching engineering design principles to students” (Lewis et al. 2006, p. 595).

3.4.6 Integration and multidisciplinary learning

In Engineering Design Methods; Strategies for Product Design, Nigel Cross noted that “successful design can only be accomplished by an integration of the skills of both engineering and industrial designers” (Cross 2000, p. 203). This is particularly true of new product development where multi-disciplinary teams engage to realise complex product solutions. The Product Design Engineering curriculum recognises this need with its integrated learning model.

There is emerging evidence that integrated learning is an ideal pedagogical model due to cross-curricula connections and student exposure to diverse and contradictory positions and environments. “The implementation of integrated curricula has helped expand the use of cooperative learning and student teams, especially in design projects. The use of these pedagogical approaches...have likely played a role in improved retention and improved learning outcomes” (Froyd et al. 2005, p. 155). In this regard, reform may be necessary within engineering to create integrated learning curricula that encourage new synergies and interdisciplinary collaboration.

3.4.7 An alternate engineering pedagogy

The global Product Design Engineering programs represent a different approach to engineering education. These courses have been successful with the integration of ‘designerly ways’ into engineering curricula without compromising the integrity of engineering science. Contrary to expectations, Product Design Engineering students are not merely generalists, but appear to be equally adept at technical engineering, despite the reduction of engineering theory in the curriculum, due to their increased capacity to apply their knowledge to practice. This is a result of curricula that offers extensive design project experience, develops sketching ability and a reflective approach, fosters creativity and uses engineering science to resolve design problems.

The PDE product development approach differs from that of the industrial design students in that products are designed from the ‘inside out’ – the product architecture is specified and engineered before the product is designed. This ensures that the processes of engineering methodology are fully integrated into the design process.
Resultantly, student design outcomes tend to be more technical in nature than those presented by industrial design students, as is evident in the following images (Figures 3.5 and 3.6). Designs are typically based around a technical innovation rather than being driven by a styling direction.

Figure 3.5: An innovative solution – an equestrian neck protector that utilises shear thickening fluid to transform a flexible helmet to shoulder brace into a rigid support to reduce neck injuries. (image source: 3D-CAD image by final year Swinburne Product Design Engineering student)

Figure 3.6: A creative approach to shared public bicycle schemes – an original mechanical design for the bicycle which integrates with a well resolved supporting infrastructure that includes racking/locking and payment system and service system.
(image source: 3D-CAD image by final year Product Design Engineering student)

The Product Design Engineering paradigm occupies a unique position, juxtaposed between the 'adaptive' design space of the engineer and the 'new' design space of the industrial designer. Consequently, this multi-disciplinary course is not without its cultural and pedagogical issues. The nature of design and engineering processes are disparate, as are the specific aptitudes required for successful professional practice. Nevertheless Product Design Engineering graduates appear to have successfully bridged the disciplines by integrating the intuitive design approach into a thorough and technically grounded engineering methodology.

This is evident in the innovative designs depicted in Figures 3.7 and 3.8. In these final year project outcomes (by students at Strathclyde University, Glasgow and Swinburne University) technically innovative solutions are integrated in well resolved equipment designs. These 'technical' products utilise innovative applications of engineering theory, but with high level consideration of user needs and user-product interaction. What is also evident is a degree of lateral thinking which has resulted in 'clean sheet' designs, which owe little to previous solutions.

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Figure 3.7: A remote controlled roof inspection robot that uses a worm drive system to manoeuvre on corrugated roofing. A creative solution that eliminates the inherent risks of such hazardous work. (image source: University of Strathclyde final year Product Design Engineering student).

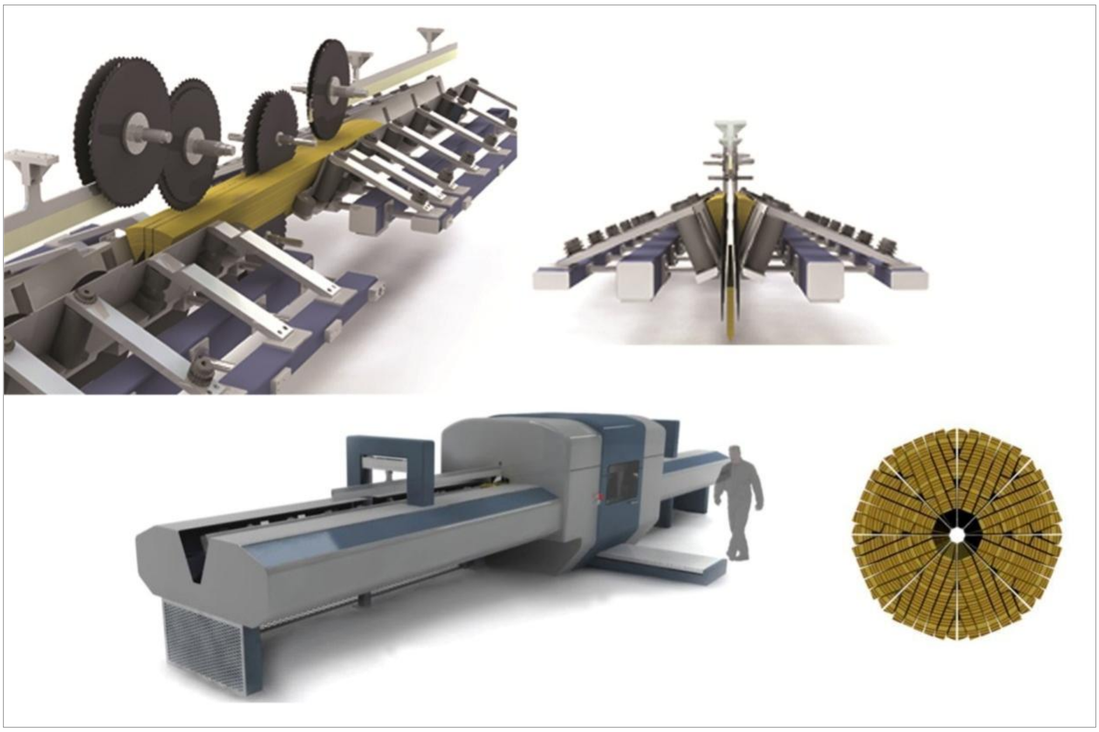

Figure 3.8: Innovation in action – Radial sector quarter-saw timber milling that delivers higher quality boards (with perpendicular grain/surface alignment) and a greater timber yield per log. (image source: Swinburne final year Product Design Engineering student)

3.5 Drawing skills for Product Design Engineers

Engineers contribute to the product design and development environment with new roles and increasing responsibilities (Hong et al. 2005). Graduates of new engineering disciplines such as Product Design Engineering are expected to be creative designers, highly competent in drawing for explorative and investigative processes, technical communication and functional explanation. These skills, introduced to the Product Design Engineering curricula through the 'industrial design' course component are supplementary to traditional engineering skills but are increasingly required by all engineers engaged in product design.

The focus on creativity and sketching within the Product Design Engineering program underlines the potential contribution of industrial design to engineering curricula, and ensures graduates with appropriate skills for new product development.

3.6 Emphasising sketching and creativity in engineering curricula

Sketching has been described as the 'first language of designers' (Bucciarelli 2002) and is a critical skill for engineers and designers as it enables the multiple social and cognitive functions represented by drawing within product design and development. Drawing acumen is considered by industry as a core and indispensible skill in product design, as it is highly efficient and free of the constraints imposed by sequential and logic based digital processes. It enables abstraction, embraces ambiguity, facilitates exploration and unexpected outcomes and provokes creativity through reflection and reinterpretation (de Vere et al. 2011).

Design acumen and creativity is enhanced by sketching and ideation activities. It is essential that engineering curricula fosters creativity and focuses on design, if our graduate engineers are to be not just technically competent, but innovative. Engineering innovation emerges from a creative process driven to seek uniqueness, where unusual ideas, unconventional methodology and unexpected implications are evident (Cropley et al. 2000). It is therefore apparent that any lack of ability to use drawing for creative exploration, reflection or communication can limit creativity, and constrain innovation and the efficiency of the design process.

However digital design processes (i.e. CAD) have significantly impacted on the sketching skills of design and engineering students. The persuasiveness of screen-based outcomes has led to an industry observed decline in drawing skill acquisition. Some may question the need for (or indeed relevance) of drawing skills in an environment of increasingly capable digital design tools, but this ignores the basic tenement that sketching allows abstraction of idea development and facilitates the creative and reflective process through external representation of the iterative design ideation process.

There is evidence that sketching plays a significant role in design creativity, free of the technical constraints imposed by digital tools, it allows multiple and simultaneous iterations to occur promptly and efficiently. The externalisation of thoughts plays an important role in the design process allowing designers to reinterpret their ideation. This 'interaction' between designers and their sketches noted by Purcell and Gero (1998), is essential to creativity. Sketching therefore is much more than an ideation documentation process, rather it facilitates a "higher level of abstraction and reflection, facilitating creativity and innovation" (de Vere et al. 2011, p. 227).

Without sketching ability, engineers may not unearth the unintended consequences that inspire the design exploratory process through 'the reflective conversation with the situation' (Schon et al. 1992). Ullman et.al (1990) found that "in engineering education, results point to the importance of being able to represent design concepts graphically" (p. 273), surmising that the design process can be limited by inability to use graphics as a cognitive extension. This is supported by the findings of Verstijnen and Hennessey (1998) who found that 'expert' sketchers more easily translate initial thoughts to design intent though a fluid and unencumbered progression. Engaging in the ideation process without excessive concentration on drawing technique, frees the mind for abstract exploration and reflection, facilitating creativity and innovation.

In the comparative evaluation study of the problem solving abilities of final year Mechanical Engineering and Product Design Engineering students (discussed in Chapter Six), it was found that the inclusion of 'designerly ways' into the Product Design Engineering curricula had greatly enhanced engineering student creativity. It was evident in the evaluation that trained sketchers were more comfortable and confident with creative design process, easily articulating and developing their ideas into technically well-resolved product concepts. It was also apparent, as noted by Dym (1999), that sketching can be a motivating factor in engineering learning.
"This implies the need for training…in the ability to represent concepts that are more abstract and better represented as sketches" (Ullman et al. 1990, p. 273).

Despite the findings linking drawing and design creativity, it is uncommon for engineering curricula to specifically foster freehand drawing skills, limiting the potential of engineering graduates to fully exploit their creativity, and explore and communicate design possibilities (Cropley et al. 2000). Insufficient training in creative design skills, such as sketching, is consistent with a lack of design emphasis in most engineering curricula as identified by Dym et al (2005).

Despite the increasing contribution of digital tools to product design, especially in the area of product visualisation, there appears to be a persuasive argument for the inclusion, or retention of drawing teaching to enhance engineering creativity and facilitate student confidence and design articulation. As sketching facilitates the creative shift to new alternatives (Goel 1995), it is vital that engineers develop into competent sketchers, capable of coherent expression of unformed ideas and design intent. Yet many engineering faculties and students disregard the exploratory possibilities that sketching offers in the creative process, relying instead on CAD, denying them opportunity to unlock their creative potential.

3.7 The importance of sketching in product design

In product design it is critical that students are proficient at creative exploration and critical reflection, and are articulate communicators of design intent. “A sketch or more formal drawing can be considered as part of the language of design” (Bucciarelli 2002, p. 225). Sketching activities addressing a range of situation and design progression needs, allow designers to externalise ideas, convey ideas metaphorically and express abstract elements and relations (Tversky 2002).

The contribution of sketching in product design and development is not limited to creative ideation, but impacts throughout all stages of the product design process. Drawing contributes to the quick and efficient resolution of technical and functional details, graphic representation of user-product interaction, form refinement and communication through explanatory drawing. Sketching can open communication channels, validate conceptual designs and advance new ideas.

Sketches help the designer to achieve not only ‘vertical transformations’ in the sequential development of a design concept, but also ‘lateral transformations’ within the solution space (Goel 1995). Sketching is a dialogue between reflective criticism and analogical reasoning and reinterpretation, that results in a gradual transformation of the images until the designer is satisfied with the coherence of the design. Goldschmidt (1991) proposes that “the inherently creative process of form production seems to result from a special, systematic causal relationship between two modalities of visual reasoning, induced by sketching” (p. 140). Fish and Scrivener (1990, p. 118), found that “sketching amplifies the mind’s ability to translate abstract propositional/descriptive information into concrete visual/depictive information.”

The fluency and flexibility of sketching produces implied, inexact or abstract representations of design possibilities, affording the designer greater freedom for experimentation, exploration and discarding of ideas to pursue new possibilities, than is evident in CAD processes. This early ambiguity avoids premature crystallisation of ideas which may constrain creativity by restricting divergent thinking, preventing the emergence of alternatives. (Goel 1995)

3.8 Roles of Sketching

Whilst there is no doubt as to the impact and influence of CAD in the product design and development cycle, particularly for detail design and documentation, drawing is still a powerful tool in the hands of the engineering designer. Free of the constraints of the sequential and logic based processes of the digital interface, it allows multiple iterations to occur simultaneously and almost instantly.

Ferguson (1992) identifies three kinds of sketches in creative design; the thinking sketch, the talking sketch and the prescriptive sketch. The thinking sketch supports and focuses individual thoughts, the talking sketch supports discussion, amongst the design team, and the prescriptive sketch communicates design intent to those outside the design process. To this Ullman *et al* (1990) adds storage; the drawing's purpose to "archive the geometric form of the design" (p. 264).

Sketching in product design and development has many functions which embrace and extend Ferguson and Ullman's characterisations. Drawing activities can be defined into specific roles and contexts, all of which occur in specific stages of the product design process, as follows:

- investigative and explorative drawing (ideation)
- technical and functional drawing (resolution)
- explanatory or instructional drawing (communication)
- form giving or aesthetic styling
- persuasive drawing (the contextual hero or sell image)

3.8.1 Investigative and explorative drawing

The ideation stage of new product development uses investigative sketching initially as the designer researches and defines the problem, before moving into concept generation through explorative sketching of solutions, functions and form proposals. In the sketches below, a Glasgow School of Art PDE student (Figure 3.9) shows aesthetic explorative process, whilst a Swinburne student (Figure 3.10) uses an investigative drawing process to explore aesthetics, product configuration, user-product interaction and functionality in a free-ranging and unconstrained manner.

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Figure 3.9: explorative ideation sketching showing aesthetic exploration (image source: concept drawings generated by Glasgow School of Art PDE student)

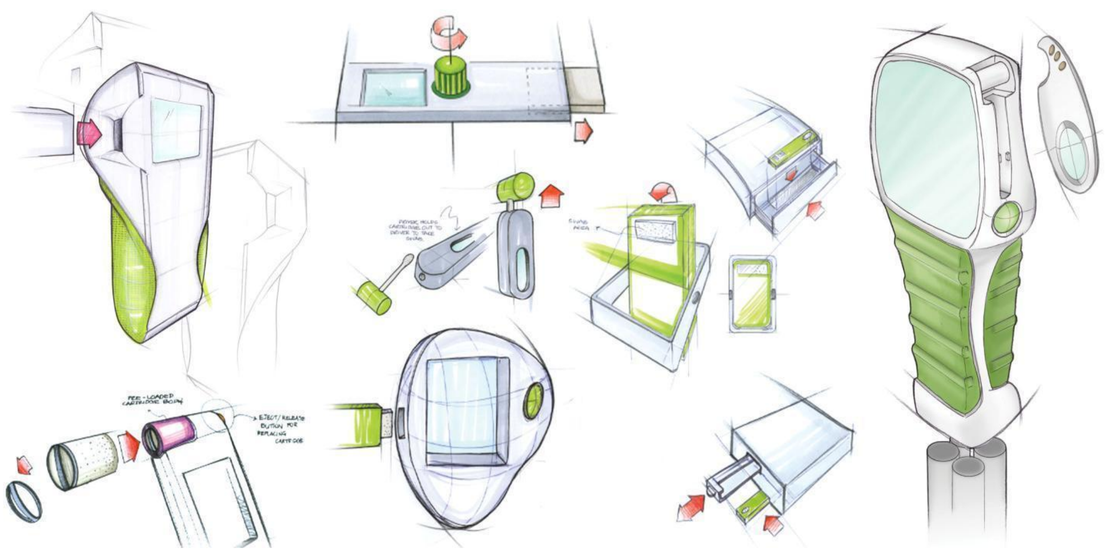


Figure 3.10: ideation sketching showing exploration of function, aesthetics, product configuration and user-interaction (image source: concept drawings generated by Swinburne PDE student)

The ability for a designer or engineer to quickly capture ideation in diagrammatical form is critical, whether the activity is concept generation or exploring functional possibilities. These types of drawings serve to:

- allow ‘free’ exploration of possibilities,
- support the investigation of new alternatives,
- generate, capture and document the emerging design intent,
- allow critical analysis (reflection in action), and
- facilitate development and improvement.

They also serve to document the creative process and allow a person outside the process (i.e. a client) to understand and engage with the exploratory journey.

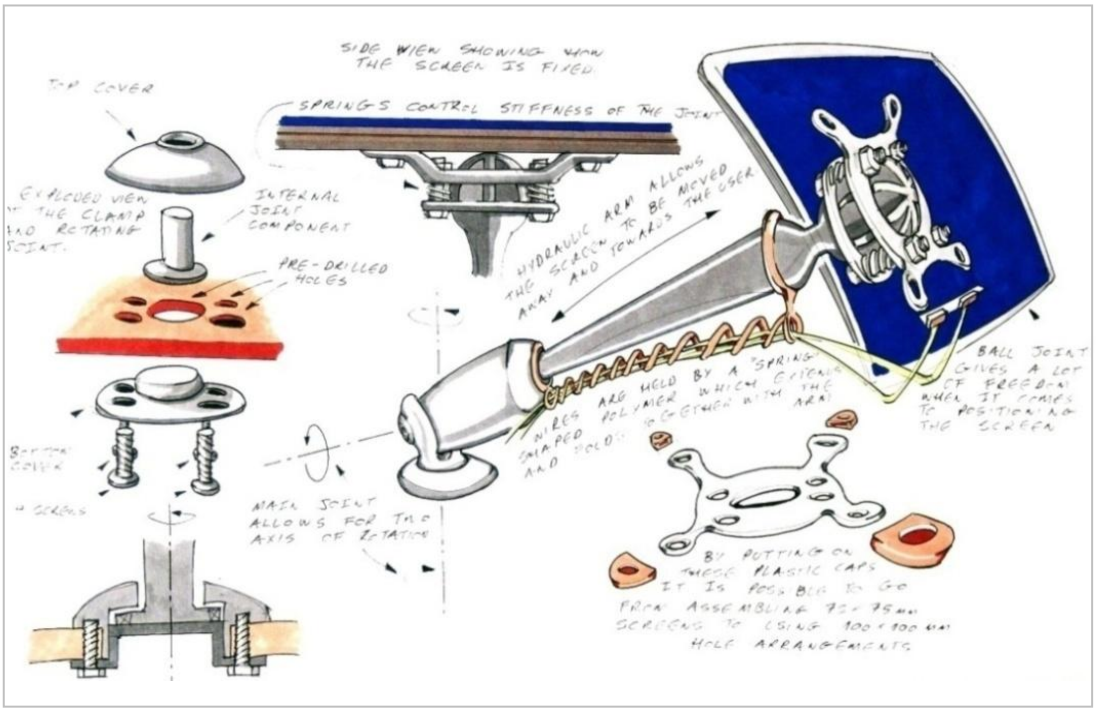
3.8.2 Technical sketching

Technical sketching (as seen in Figures 3.11 and 3.12) is a style of drawing that is either investigative or communicative of features and function through the use of exploded perspectives and mechanical design sketching, and is commonly utilised both in the ideation and design detailing stages.

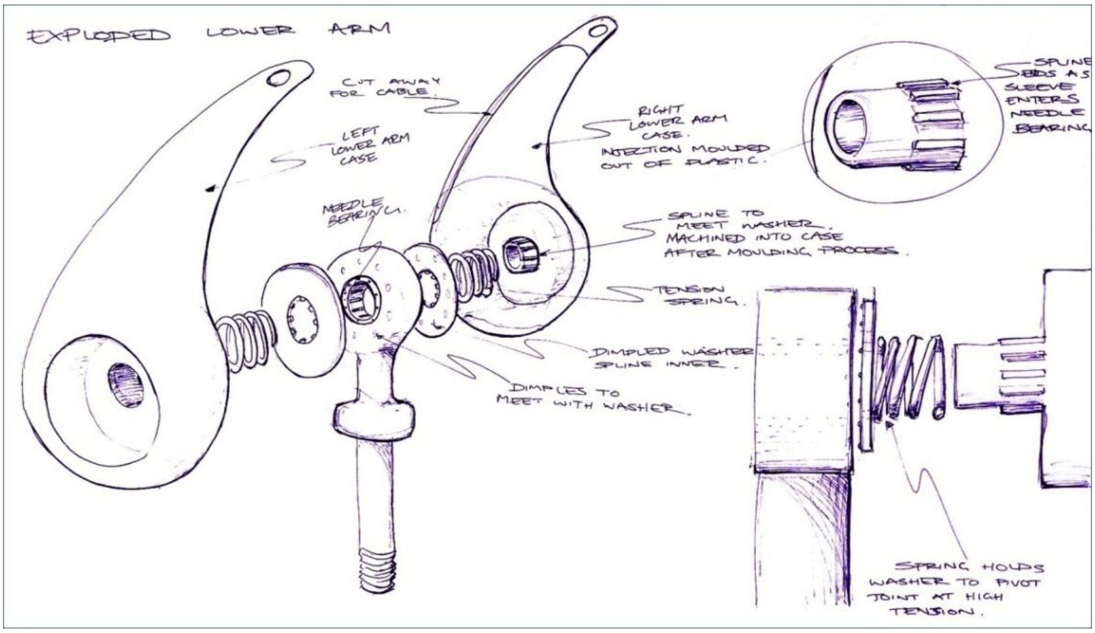
Technical sketching is used in ‘conversation with one’s self’ during the functional resolution process in conjunction with CAD, but also provides an excellent tool for quick and effective communication with technical or production staff.

Technical sketching can be used to:

- develop mechanical systems and functionality,
- resolve component details and assembly methods,
- understand component relationships,
- investigate issues relating to the resolution of the product or its parts,
- explore functional or technical alternatives, and
- communicate function or assembly to others.



Figures 3.11(above) and 3.12 (below): technical drawing showing the resolution of technical and assembly details (image source: drawing generated by year 2 Product Design Engineering students)



3.8.3 Explanatory or instructional drawings

These sketches are communicative and are used to impart function, assembly or user sequences. These drawings are typically not part of the product design process, rather they occur later to provide information to users and may involve sequential explanation or product interaction description.

Drawings such as those shown below are typically generated after the design and development process is complete, purely for communication purposes, and are used to explain or instruct the user. Typical applications could be for example, a manufacturing sequence or consumer assembly procedure or a series of steps in the user-product interaction (as shown in the instructional drawing in Figure 3.13).

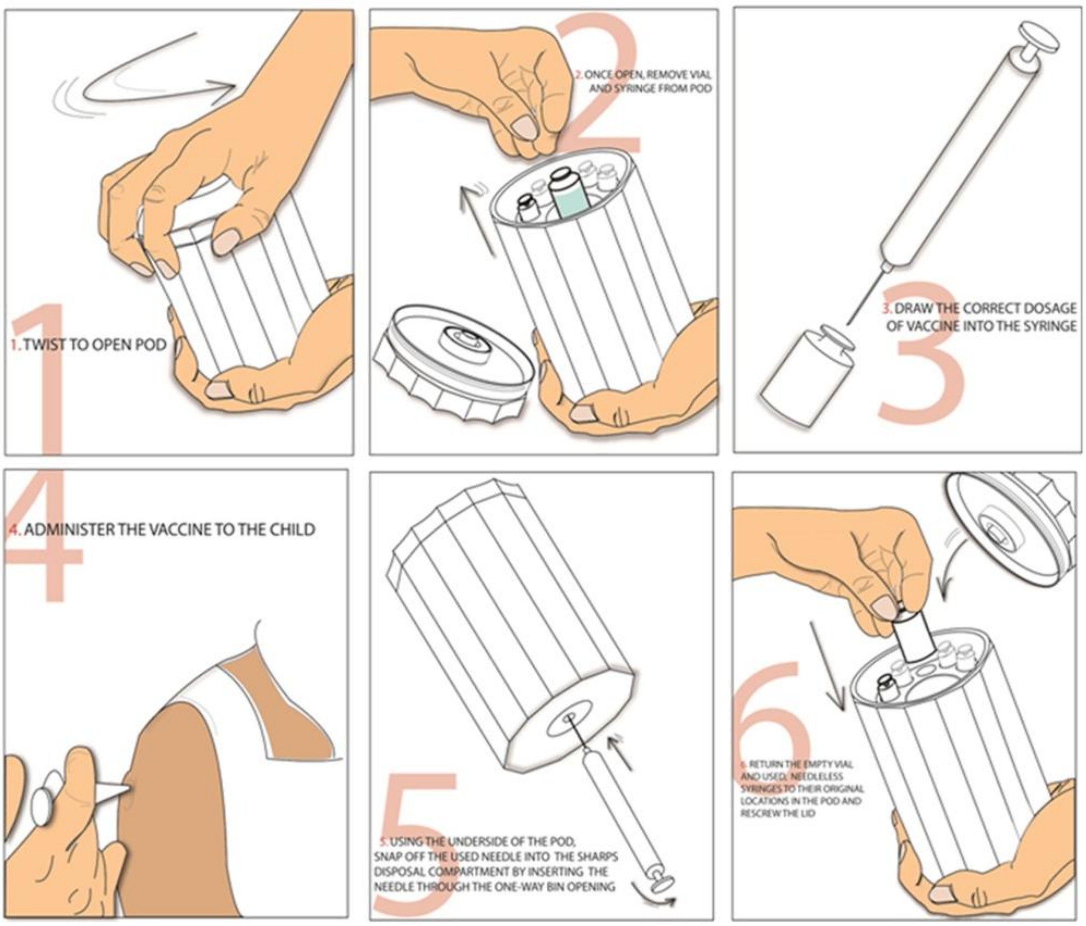


Figure 3.13: instructional drawing communicating product / user interaction
(image source: drawing generated by year 3 Product Design Engineering students)

3.8.4 Form-giving

Form giving or aesthetic styling drawing involves the development of aesthetic styling for the appearance of the product and may occur simultaneously or sequentially with functional design in the ideation, design development and embodiment stages.

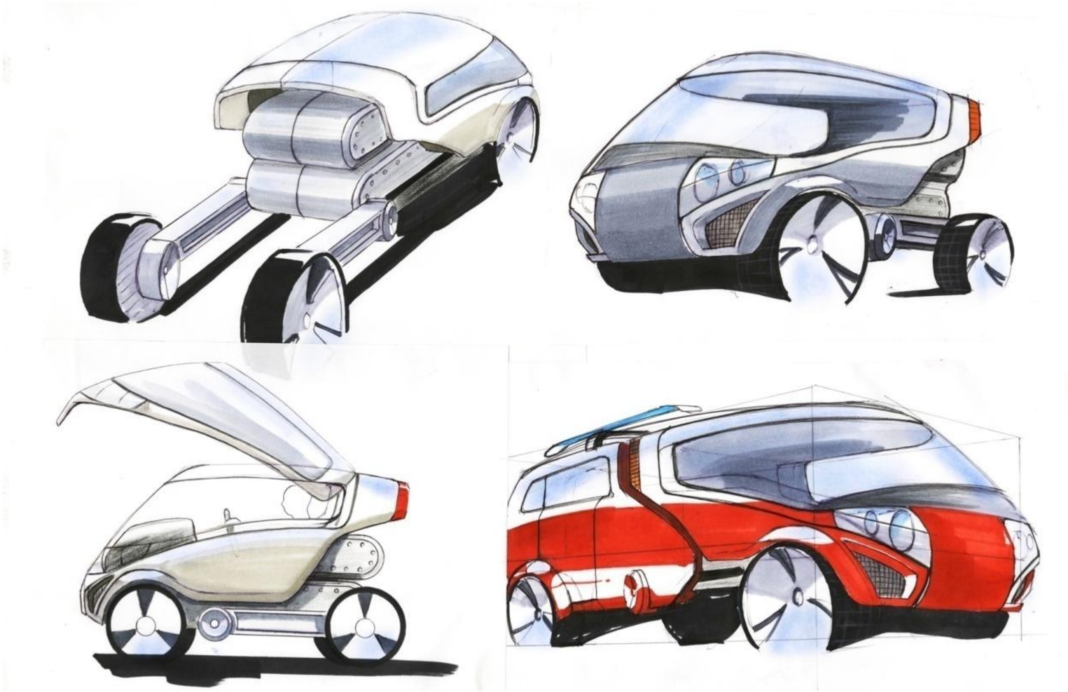


Figure 3.14: conceptual styling / form giving drawing
(image source: drawing generated by final year Product Design Engineering student)

This style of drawing as shown in Figure 3.14 (above) and Figure 3.15 (below) may be outside the scope of employer expectations of engineers, however they represent the ability to give definitive form to a design and establish 'identity,' market appeal and product differentiation.

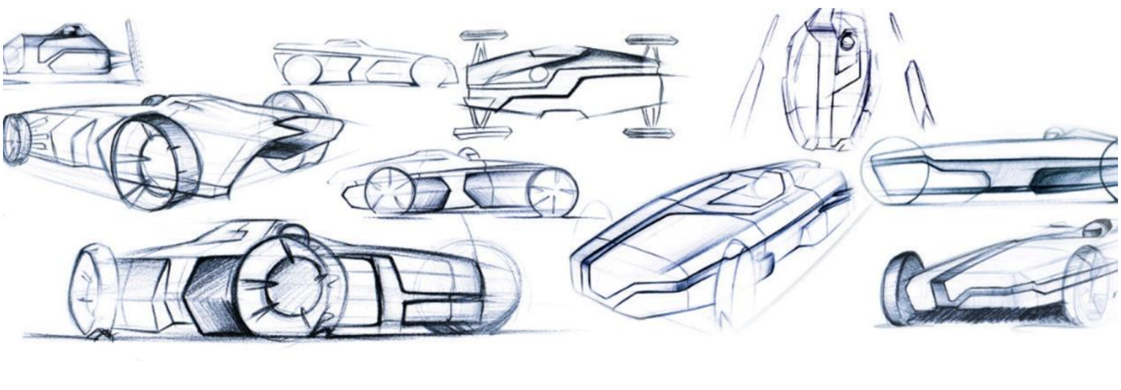


Figure 3.15: concept sketches – exploring form
(image source: drawing generated by year 3 Product Design Engineering student)

3.8.5 Persuasive drawing involves the generation of detailed high quality contextual images (such as the one below in Figure 3.16) which are used to ‘champion’ the proposed design. It is in this area that 3D-CAD rendered images have had the most impact on design studio drawing practice.

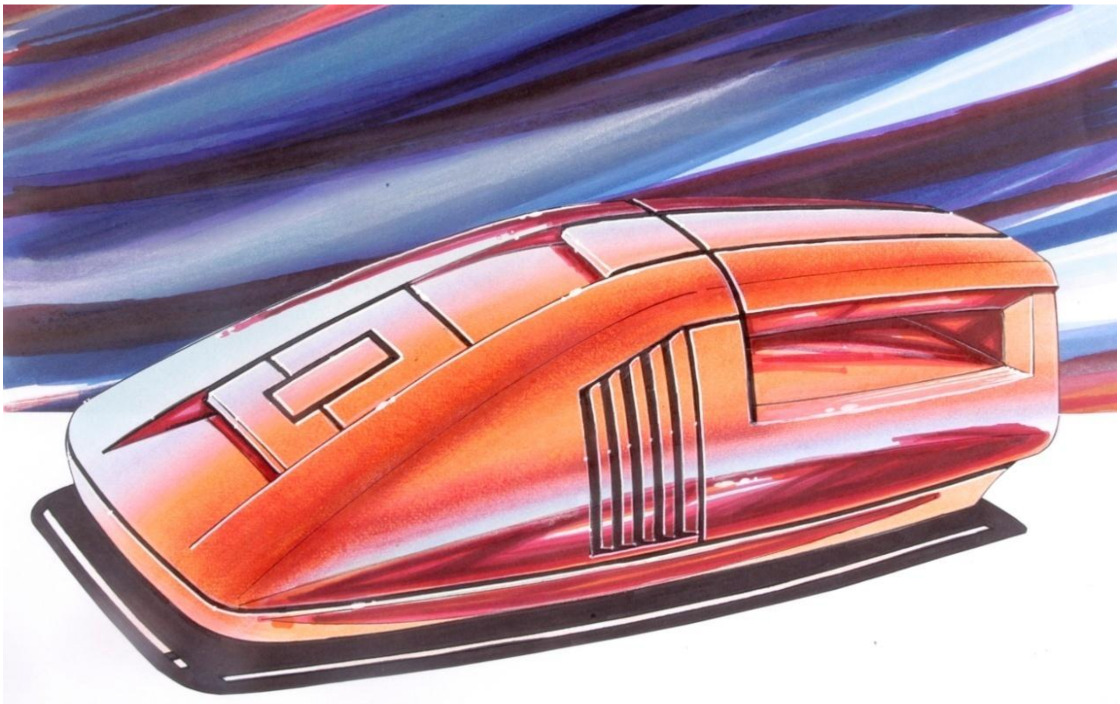


Figure 3.16: rendered ‘hero’ image
(image source: drawing generated by year 1 Product Design Engineering student)

It now relatively uncommon for this type of manual drawing (using pen, marker and pastel) as shown above in Figure 3.16, to be used to ‘sell’ the design proposal, as the advance of digital technology has enabled fast product representation with multiple variations, which is laborious and time consuming when executed by hand.

However this style of sketching is now experiencing a renaissance, but not in paper-based form. These traditional drawings skills can now be used in conjunction with digital sketching tools (such tablet monitor/stylus interfaces) as shown below in Figure 3.17 to create fast product depiction in 2D digital images that can be freely manipulated and copied allowing multiple iterations and fast exploration of detail. But the traditional sketching skills and techniques of surface representation need to be taught before students can use the new technology effectively.

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Figure 3.17: digital sketch using Wacom tablet monitor and digital stylus
(image source: design lecturer Bernie Walsh)

3.9 Developing an engineering drawing culture

3.9.1 A cultural shift

The impact of the new discipline of Product Design Engineering on product development has been significant, with many graduates challenging the composition and internal roles of product design and development teams. The design aptitude and sketching acumen of these engineering graduates has seen them occupy roles traditionally reserved for industrial designers. This has resulted in the need for a greater emphasis on drawing skills within the curriculum. The emergence of this new paradigm of design engineer has revealed that many engineering graduates are typically poorly equipped for the practice of engineering in a product design and development environment; lacking the obligatory creativity and design ability.

3.9.2 Expectations

It is apparent that visual 'artistic' skills are important to engineering design processes and it is recognised that cognitive functions and creative pursuits may be hampered by the introduction of CAD too early in the design process (Henderson 1991; Stewart 1999).

Typically in the PDE curriculum, perspective sketching and rendering are integrated early into the learning experience, usually from the initial semester through to the final year, whilst design projects expect hand sketching throughout, with a shift to CAD only at the stage of product definition and documentation.

It is apparent through discussions with course leaders and PDE employers, that the design fluency of the PDE graduates, particularly in product design environments, has led employers to a high level of expertise in both engineering and design, including front-end conceptual design. This changing or emerging role for engineering has driven the recent introduction of a new sketching program at Swinburne (detailed in Case Study 2 at the end of this chapter), which aims to develop a stronger drawing culture amongst the engineering student community.

3.10 Discussion

Cropley and Cropley (2000) in their investigation of engineering student creativity, suggested that many engineering graduates are unsuitable for employment due to skill deficiencies in creativity and problem solving. It is probable, based on findings by Verstijnen and Hennessey (1998), that limited instruction in sketching techniques in education may be restraining the creative potential of engineering graduates. Without sketching ability, engineers cannot benefit from the abstract exploration and reflection that facilitates the emergence of unintended consequences, and the fluid, unencumbered progression from idea to design intent that is facilitated by drawing.

Despite this, there is little evidence that sketching, the primary tool for engineering designers to articulate their thoughts for problem framing, discussion and reflection, is valued in traditional engineering education, despite significant research linking sketching to creativity (de Vere et al. 2010). Yet it is imperative that engineering students become proficient in sketching and ideation techniques if we are to develop a new generation of creative and reflective engineering designers.

It is therefore important that student reliance on 3D-CAD is reduced in the ideation stages. 3D modelling, although invaluable in the detail design process, imposes a structured methodology upon the user, restricting exploration and abstraction, stifling creativity in product ideation. Sketching is not only the tool of creativity and communication, but can also be a motivating factor in learning, resulting in more creative engineering graduates.

One of the benefits of multidisciplinary engineering curricula such as Product Design Engineering is that the inclusion of design curricula introduces critical skills in and design sketching into the student methodology.

3.11 Conclusion

Chapter one identified creativity and design skills (including sketching ability) as key graduate attributes for engineers engaged in new product development. The global PDE courses exemplify how the joint requirements of industry and engineering regulators can be addressed through targeted engineering curricula. These new engineering pedagogies, which develop specific graduate attributes in design, creativity and innovation, are proving successful in new product development.

This chapter demonstrates that Product Design Engineering is an example of new engineering curricula that fosters creativity and innovation through structured integration of design throughout the curriculum, with design project-based learning utilised extensively to teach the *practice* of engineering. Accordingly, the curriculum meets requirements for creativity and design acumen in new product development.

The following Case Study 2 describes teaching initiatives within the Swinburne PDE program which aim to develop a drawing culture amongst the engineering student cohort and enhance creativity through skills–based curricula. It provides an example of how a curriculum can respond to specific industry requirements (e.g. sketching ability) whilst simultaneously enhancing critical graduate attributes (e.g. creativity).

In Chapter Four, *Ethical Engineering*, the development of the other key graduate attributes of sustainability and social responsibility will be addressed.

Case Study 2: Developing a sketching curriculum

Introduction

Chapter three identified the importance of sketching in product design, as both a means of communication and to enhance creativity (refer Section3.7). This case study examines the development of a new drawing curriculum at Swinburne University of Technology, aimed at Product Design Engineering students. It aims to illustrate how a drawing culture can be initiated amongst an engineering student cohort and how essential creative skills can be developed though a targeted teaching program delivered within an existing curriculum structure.

SketchFest – a new drawing curriculum

The 'SketchFest' curriculum initiative was conceived with two primary objectives in mind. Firstly, the enhancement of existing freehand sketching skills within the Product Design Engineering student cohort to a level where creativity, conceptual design processes and communication of design intent were not impacted by drawing skill limitations. Secondly, it aimed to actively promote a culture of drawing within the engineering student community.

The Course Advisory Committee which comprises external representatives from the product design and manufacturing industries had highlighted students and graduate deficiencies in perspective drawing and creativity. The 'SketchFest' curriculum addresses these employer concerns through a program that embeds sketching skill development throughout the Product Design Engineering learning journey.

The 'SketchFest' modules teach ideation sketching, styling and form giving, technical sketching and explanatory drawing. The modules which were originally delivered to final year Product Design Engineering students as a remedial measure, are now structured throughout the PDE and Industrial Design programs, albeit with differing emphasis. The Product Design Engineering SketchFest modules focus more on the use of freehand-drawing for technical resolution and explanatory communication, rather than aesthetic styling. This sketching curriculum augments existing drawing skills, introduces new techniques and promotes student awareness of the importance of sketching in product design and development.

SketchFest v1 – the initial trials

The initial SketchFest modules targeted final year Product Design Engineering students whose earlier projects had revealed a lack of sketching competency. Whilst these twenty-five students were competent at technical product resolution, it was evident that their ideation and form giving was limited by their drawing ability.

It was possible that this lack of demonstrated skill in the 'fuzzy front end' was exacerbated by previous reliance on CAD and a lack of explorative or reflective practice. Although these students had been exposed to 'designerly ways' since the beginning of their course, it was apparent that they valued sketching less than industrial design students, perhaps feeling that expertise in sketching was not critical to their overall ability or employability. However, academic staff and the industry representatives on the course advisory committee disagreed, highlighting sketching as a key graduate attribute, as identified in Chapter One.

Whilst design engineers typically are not expected to be able to produce 'persuasive' or product hero drawings, such as those generated by industrial designers for client or investor approval, there are many forms of sketching that are essential to the effective conceptualisation, technical development and implementation of a product; predominantly product ideation, resolution and communication.

The four teaching modules were designed to provide a range of sketching experiences, with students in each session being offered one of four distinct product categories from which to choose a product challenge. These were not revealed until class commencement, to ensure that outcomes were representative of the allowed timeframe. Differing materials, user needs, environmental and ergonomic constraints and functional requirements ensured that the challenges, whilst relatively constrained, encouraged creativity, innovation and originality. Students were expected to produce new designs and to not fixate on existing solutions.

The SketchFest criteria aimed to:

- focus solely on ideation and sketching, independent of the normal design project constraints,
- enhance and develop existing skills,
- introduce commercially realistic pressure and time constraints to the students design processes, and
- identify skills deficiencies and raise awareness of the value of sketching

Initial instruction

The first session consisted of a briefing session and introduction to quick perspective sketching techniques. Initial tutoring utilised in-class lecturer expertise combined with on-line tutorials from the 'ID Sketching' website, (http://www.idsketching.com) which includes the 'sketch-a-day' gallery and drawing and rendering demonstrations by Spencer Nugent (http://vimeo.com/idsketching/videos). Students used this period to practice and refresh techniques before the assessable activities commenced.

Studio Activity

SketchFest was run as a four-part intensive course, primarily aimed at improving graduate skills in sketching and quick ideation during final semester design studios. As the ability to rapidly generate conceptual designs is an essential industry skill for product designers, the first SketchFests were run within a two-hour design studio as intensive ideation sessions. By limiting available time, SketchFest aimed to introduce industry pressure and time constraints into students' design processes. In this short timeframe, it was expected that outcomes would be highly conceptual, and may lack technical consideration; this was acceptable as the main intent was to stimulate creativity and develop sketching confidence and ability through explorative ideation.

Each two hour SketchFest session required students to respond to a simple brief with a series of hand-drawn perspective ideation sketches. Students were tutored throughout each module by two experienced industrial designers who suggested and demonstrated drawing and ideation techniques as appropriate. Sessions concluded with a brief pin-up review and reflective discussion session. The first two modules were run on consecutive weeks, followed by a week of review and individual consultation before the final two exercises.

It was anticipated that the exercise would also generate not only useful content for graduate portfolios but more importantly, evidence of the ability to deliver design ideation in industry appropriate timeframes. Students were encouraged to incorporate SketchFest pages into their portfolios and to further develop their designs at a later stage using 3D-CAD or digital visualisation tools.

Initial design challenges

Each week featured a different design challenge, followed by a pin-up review and reflection session. In each session students were introduced to a specified product category from which they could choose one of four design ideation challenges.

The design challenges were not open-ended problems that would require time consuming investigation or problem scoping. Instead they focused on familiar products within established product categories. Students were required to produce three A3 pages of fresh and original designs, not adaptive iterations of existing product solutions.

The product categories used for the SketchFest v1 were:

Exercise 1: consumer electronics – one of either headphones, digital video camera, video game controller or webcam

Exercise 2: industrial equipment –safety helmet / facemask, cordless drill/ screwdriver, work lantern or lawnmower (hand-powered or motorised)

Exercise 3: apparel – sunglasses/ski goggles, backpack/courier satchel, binoculars or wearable communications device/watch

Exercise 4: packaging - reusable water bottle, 2lt milk bottle with integrated pourer, easy open can (for elderly users) or men’s cologne bottle

Whilst it may be observed that these products did not represent significant engineering or technical challenges, this was a calculated decision. As the primary aim of SketchFest was to improve sketching and to develop quick ideation skills (within a two-hour timeframe), it was crucial that students could start the ideation process immediately upon receiving the brief.

Deliverables included both perspective and elevation sketching and specified the application of colour through quick marker rendering techniques. It was intended that these ideation pages be of sufficient quality of execution to be suitable for discussion with a client, not just for personal reflection. Product concepts were to be communicated contextually with the inclusion of a human figure, hand etc as appropriate to communicate product interaction and functional sequence.

Analysis of Process and Outcomes from SketchFest v1

Studio observations

Students responded to the teaching module initially with some hesitation and uncertainty. Whilst sketching had been part of their product design and development process for many years, it was not since first year that they had been specifically assessed on drawing output, all assessments involving sketching were typically part of other project deliverables.

Consequently, many poor sketchers had been able to progress through the course unimpeded by lack of drawing acumen, dependent on competency in 3D-CAD, satisfactory product resolution skills and long project lead-times. It was these deficiencies that this new drawing curricula sought to address. The need to produce ‘on-demand’ with tight timeframes took students out of their comfort zone and highlighted individual skill deficiencies.

It was immediately apparent in Exercise One that many students, even those with a history of competent drawing and well resolved product solutions, struggled to articulate their ideas within the two-hour timeframe.

This was principally due to one of two main reasons:

- the pressure of the timeframe adversely affecting their ability to abstract and ideate (“I just don’t have any ideas”), or
- difficulty with expressing complex forms in appropriate perspective viewpoints leading to a slump in the quality of drawing (“I usually spend time setting up perspectives, templates etc”).

The introduction of the program was justified by the initial findings which supported the lecturers perceptions of students' abilities, but lecturers remained concerned that so many students, close to graduation and employment, were unable to deliver quality design concepts, on demand, on time, in what was considered to be an appropriate measure of required industry skills.

Whilst some may believe the tight timeframe unnecessarily restrictive, it was necessitated by the studio class timetabling requirements, but was also felt to be an accurate representation of the time and budget driven processes of many product design consultancies. It was also considered to be appropriate industry preparation for final year students who typically were complacent within long project gestation periods and had not yet developed efficient and industry-relevant working practices.

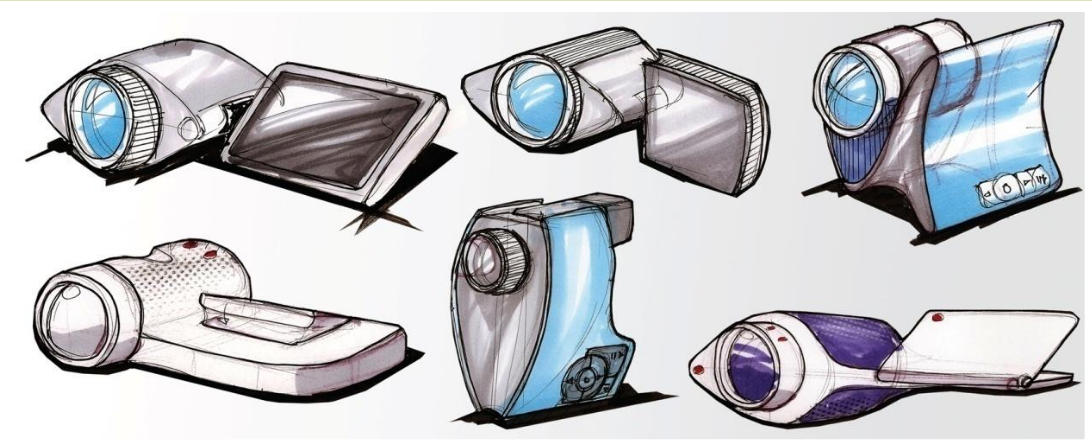

Figure Cs2.1: rapid ideation sketching – quick representations of form and configuration
(Image source: student generated sketches from two hour exercise – final year PDE student)

However, the initial trials also revealed that the good sketchers consistently delivered well-considered product ideation, as well as good drawings, supporting the findings of Verstijnen and Hennessey (1998), Fish and Scrivener (1990), Ullman et al. (1990) and others with regard to the link between drawing expertise and design creativity.

The 'expert' sketchers had more time to reflect upon and refine their designs and explore variations of feature and form, different configurations and consider user interface than those students who struggled to externalise their thoughts, as is evident in Figure Cs2.2.

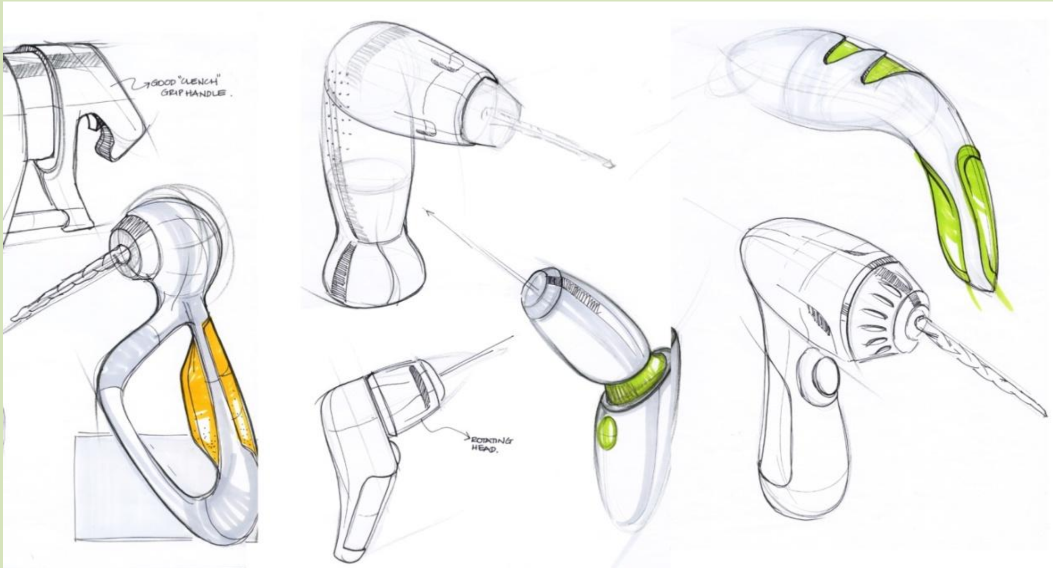

Figure Cs2.2: Proficient ideation sketching – the good sketchers had time to use reflection to develop and detail the design concepts and explore multiple configurations
(Image source: student generated sketches from two hour exercise – final year PDE student)

Assessment criteria

Assessment of the exercises was divided into two main criteria; quality of sketching and quality of ideation. Sketching was assessed against criteria that measured:

- accuracy and appropriateness of chosen perspective,
- quality and hierarchy of line work,
- appropriate use and technique of marker application,
- page layout – composition, use of negative space, graphic devices, and
- contextual citing of product in context to show user-product interaction,

whilst the ideation criteria assessed:

- quick conceptualization (generation of multiple concepts),
- diversity of ideas (investigative and explorative drawing),
- innovation (unique design ideation without fixation on known solutions), and
- aesthetics (quality of form giving/styling).

Lecturing staff were expecting to see personal development in quick perspective sketching and rendering across the duration of the program, an improvement in student confidence plus resultant enhancement of ideation quality and product communication resulting from increased drawing competency. In the following example (Figure Cs2.3), quick ideation sketches clearly communicate the benefits of drawing acumen with the contextual citing of the product clearly communicated.

Figure Cs2.3: Example of quick ideation sketching with strong contextual definition
(Image source: student generated sketches- final year Product Design Engineering student)

Analysis of outcomes

A review of student grades (see Figure Cs2.4) clearly shows the development of skills and improvement in both drawing and ideation quality.

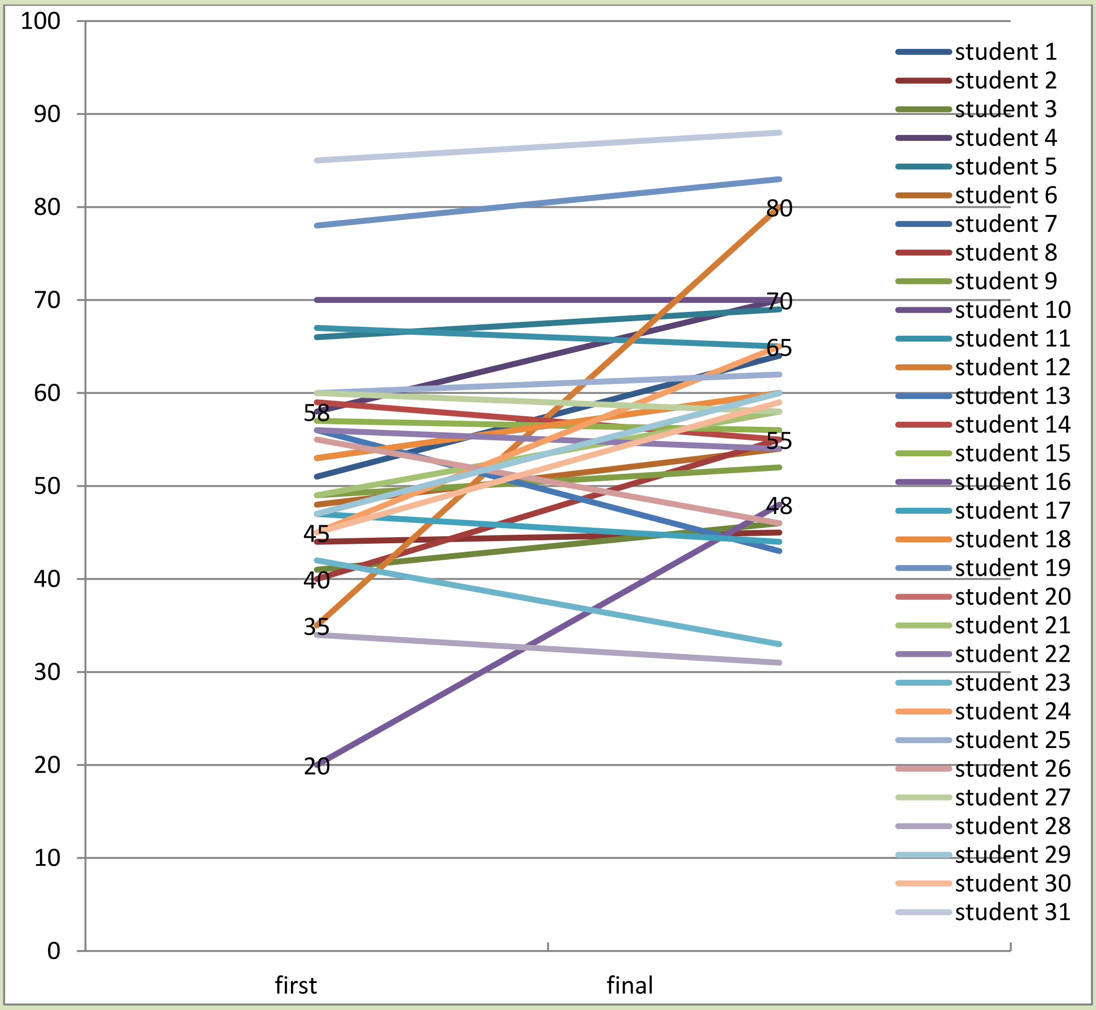

Figure Cs2.4: SketchFest results chart showing assessment differentiation from first to final exercise
(Image source: student assessment data - collated and analysed by the author)

The data in Figure Cs2.4 reveals that seventy percent of students achieved higher marks in the final two exercises than the earlier ones, and achieved average marks across the four exercises that were significantly higher than in the initial exercise. The majority of students improved their marks by at least ten percent, and one fifth of students improved markedly, with greater than twenty percent grade improvement. It should be noted that this data results from the subjective internal assessment of a small sample group of twenty-five students, however it is indicative of an overall improvement in student ability, in most cases. In instances where marks reduced, this was due to unsuccessful experimentation rather than technique deficiency.

More significant, was the observed increase in student confidence and the ‘relaxing’ of both technique and approach. It was apparent, even during the individual exercises, that students were becoming more comfortable and confident. This was evident when the three A3 pages were reviewed at the end of each session. Initial pages tended to be ‘scratchy’ and undirected whilst later pages, even though completed only an hour later, showed greater control, foresight and ideation competency. Also encouraging was evidence of reflective practice as subsequent pages demonstrated refinement of initial ideas and variations of earlier concepts.

Figure Cs2.5 clearly shows the increasing confidence and proficiency of a student during a single two-hour exercise. Whilst the initial ideation is undirected and rudimentary with two dimensional drawings and crude forms, the later sketches utilise perspective sketching and demonstrate greater control and ability with high level form-giving and more sophisticated use of line and marker rendering.

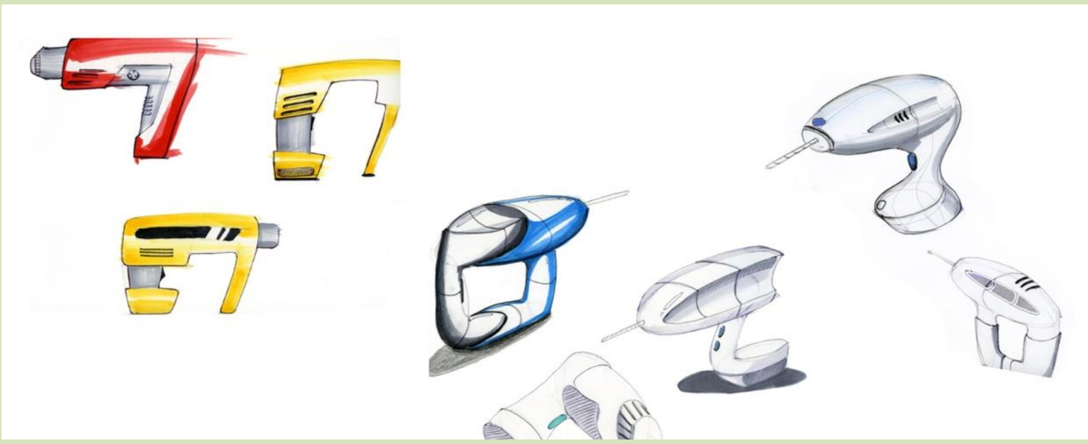

Figure Cs2.5: Confidence and proficiency emerging during two hour session - earlier sketches shown on left, later sketches on right. (Image source: final year Product Design Engineering student)

Student feedback

Despite early issues of low self-confidence and concerns regarding assessment, students applied themselves well to all of the exercises, arriving to class early and well prepared to maximise session productivity. Almost all of the students clearly demonstrated improvement in perspective sketching and resultantly their ideation skills also improved, for which they were grateful. Students appreciated the curricula innovation and felt the results validated the intent, but many questioned the timing, believing that it would have been more beneficial run earlier in their course.

Most encouraging was evidence that students had been independently working to improve their drawing skills outside class, and that they were beginning to realise that sketching aptitude was an essential industry skill, rather than a historic anachronism.

Students reported that their sketching skills had been enhanced and this was reflected in increased confidence and a more relaxed approach leading to faster and more diverse ideation. They appreciated their new found ability to provide efficient and timely design solutions under pressure, a necessary industry skill.

Industry feedback

Industry response to the initial SketchFest program was positive with both the course industry advisory committee and other employers welcoming the initiative, indicating that skills in quick sketching and ideation will greatly enhance graduate employability and productivity.

Industry representatives have requested that future drawing exercises be focussed on the areas of investigative and explorative drawing, technical and functional resolution and explanatory or instructional drawing; these being the main areas of activity for design engineers. Much was made of the need for engineers to be able to communicate their thoughts quickly and effectively though drawing in a variety of environments, ranging from the meeting room through the factory floor to the end user, without dependence on digital media.

SketchFest v2 – imbedded curricula

Following the success of the initial trials, it was apparent that an embedded approach to sketching instruction was required *throughout* the curriculum.

SketchFest Version 2 was introduced in early 2011 as a series of four modules integrated into the 2nd and 3rd year Industrial Design and Product Design Engineering design studio subjects, and also in fourth year Product Design Engineering as a remedial measure. Student and graduate deficiencies in perspective sketching, ideation, styling, explanatory and technical sketching are addressed through stand-alone teaching modules that 'plug in' to existing design studio units.

These independently assessable modules have distinct themes, providing a progressive learning experience with each semester having a unique module with a clearly defined drawing agenda for students to master before progressing. These intensive sketching modules have now run for four semesters and have created a renewed interest in freehand drawing and enhanced students ability to ideate and communicate design intent quickly.

The SketchFest v2 teaching modules

The sequential modules aim to develop confidence throughout the course and to redefine sketching as the primary form of design articulation for design progression and communication. Each three-week teaching module targets specific industry-relevant sketching functions; the distinct content of each semester negates content duplication and develops sketching skills progressively over four semesters.

Modules typically occur within the timeframe of a two or three-hour design studio class, however as the intent is to develop a drawing culture, extra-curricular development of sketches is permitted, with students submitting work in a pin-up review session during the following class. The additional time allowance enables students to rework drawings and improve technique, without the pressure of in-class completion, and encourages students to commit more time to drawing activities, resulting in greater confidence and an increased desire to attain sketching acumen.

***SketchFest module no.1: Investigative and explorative drawing** (2nd year)*

The ideation stage of product design uses investigative drawing initially as the designer researches and defines the project, before concepts are developed through explorative sketching of possible forms, functions and solutions. This second year module focuses on exploration of form and function.

In Week 1, students engage in ideation sketching using coloured pencil, before moving to fineliner and marker in week 2. In week 3 students explore form development using curvature and blends.

Figure Cs2.6: Examples of investigative and explorative ideation sketching
(Image source: drawings generated by 3rd year Product Design Engineering student)

SketchFest module no.2: Technical and functional resolution drawing

Technical (or mechanical design) sketching is either investigative or communicative of features and functions using exploded perspectives and sections in both ideation and design resolution stages. In this second year module students develop exploded perspectives moving from single axis deconstruction in week 1, to multiple axis deconstruction in week 2, and finish with representation of technical mechanisms.

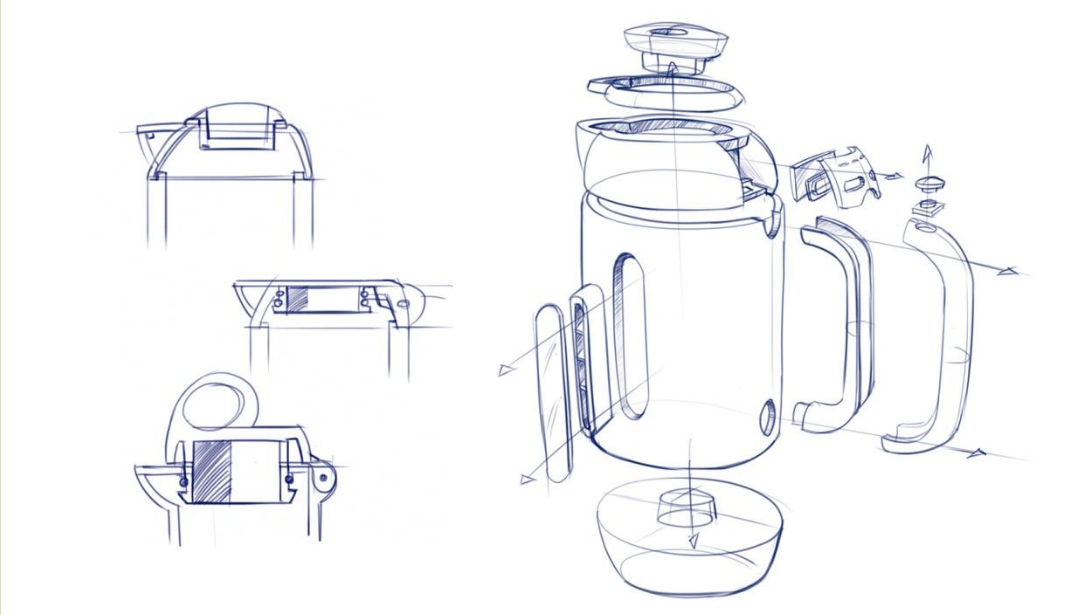

Figure Cs2.7: technical sketching showing the resolution of technical and assembly details (Image source: final year Product Design Engineering student)

SketchFest module no.3: Explanatory or instructional drawing (3rd year)

These communicative drawings are used to impart function, assembly or product-user interaction sequences. These drawing are not typically part of the product development process, but used by the designer to impart product information to users, often as a sequential description.

In this third year module, students gain experience in sketching operating sequences and product interaction drawings in week 1, user focused assembly instructions (8-10 steps) in week 2 and storyboards (e.g. product system services) in week 3.

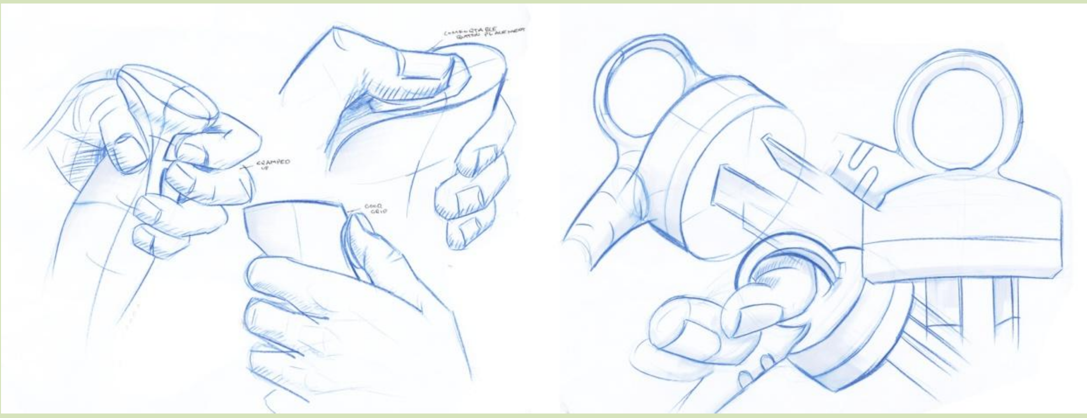

Figure Cs2.8: Example of explanatory sketching for product interaction (Image source: drawing generated by 3rd year Product Design Engineering student)

SketchFest module no. 4 – advanced styling (3rd year)

Form giving or styling drawings enable the development of product aesthetics simultaneously or sequentially with functional design drawings in the ideation, development and resolution stages.

This advanced module, whilst outside the scope of many engineering activities, recognises that many Product Design Engineering graduates are employed in dual design and engineering roles where they may be required to take responsibility for product styling in lieu of using an industrial designer. It therefore responds to these broader employer expectations of Product Design Engineering graduates, and the subsequent need for advanced skills in surface development, contours, detailing and product model variation.

Delivery

The SketchFest v2modules are delivered as in-class activities during two-hour design studio sessions with continuous lecturer engagement and feedback. Students are expected to work productively during the studio session, continue work on the exercise outside class and submit final drawings via a 'pin-up' review at the beginning of the following week's class. Although conceived as an in-class activity, it is critical that students engage in extra curricula drawing if a 'drawing culture' that is independent of project deliverables is to be developed, providing the opportunity for students to continue their work in their own time aims to achieve this.

The impact of the new sketching curricula

The introduction of SketchFest into the existing Product Design Engineering (and Industrial Design) curricula was not without its problems. Taking three weeks out of the twelve-week semester studio program significantly impacted on the time and staff resources available for design project activity. There was initial resistance from staff who were reluctant to sacrifice such a large amount of design studio time although they understood the necessity of the sketching initiative. Project timelines were shortened, placing additional pressure on students who were already feeling the burden of extra assessment tasks and the need to rapidly improve drawing skills.

The SketchFest modules were allocated significant assessment weighting; 20 percent of the overall subject marks for 2nd year modules, and 30 percent for 3rd year. This weighting combined with the separation of sketching assessment from the design projects, meant that students with good academic records (but poor sketching skills) found themselves unable to hide behind CAD skills and proficiency in product development and resolution, and thus vulnerable to poor marks and possible failure.

Whilst this was not unexpected, it was felt critical that student deficiencies in these essential industry skills were addressed promptly; this importance outweighed any short-term logistical concerns.

Reflections on SketchFest v2

It is essential that engineering graduates are effective visual communicators who can translate abstract and exploratory concepts into definitive product solutions through the medium of sketching. The SketchFest curriculum was established to achieve a level of drawing competency and enhance creativity.

Overall the SketchFest v2 curriculum has been successful with student skills and creativity improved, increased industry demand for student interns and evidence of a rejuvenation of student interest in drawing skill acquisition. As a remedial 'patch' solution it has not without implementation issues; however the results have justified the continuation and expansion of the initiative.

It is anticipated that its continued implementation will assist in developing a passionate and robust culture of drawing dependence throughout the design and development process. Student progression will be carefully monitored to ensure that the program reaches its objectives, which is to ensure that all Product Design Engineering students are efficient and accomplished sketchers and reflective practitioners.

Moving forward

Whilst sketching on traditional paper media is quick, effective and inexpensive, the emergence of new digital media tools is impacting on product design and development. The utilisation of new sketch-to-digital products including drawing tablets and digital sketching pens (such as Wacom's Inkling) are changing the way designers ideate and communicate, yet even in this new digital age of product development the importance of sketching ability is unchallenged.

In response, a new 'digital' sketching curriculum has been developed, one that will satisfy the expectations of both industry and staff in respect to graduate drawing skills, facilitate creative practice and re-energise student interest in sketching whilst embracing emerging digital practices.

Conclusion

The Course Advisory Committee and employers of PDE alumni (in Chapter 8) have revealed the importance of sketching-led creativity in the NPD workplace, and the heightened employability of engineers with these skills. The SketchFest curriculum initiative has proved successful in the preparation of graduates for roles in new product development, addressing the key graduate attributes of creativity and sketching identified in Chapter One.

Chapter four: Ethical engineering

4.1 Overview

Chapter four examines the need for engineers in new product development to be both sustainable and socially responsible; key graduate attributes identified in the earlier stages of this research.

This chapter draws from a peer-reviewed conference paper presented in Denmark in August 2011 at the 18th International Conference on Engineering Design (ICED11), organised by the Design Society and the Technical University of Denmark (DTU).

> de Vere, I., Kapoor, A., Melles, G. (2011) An Ethical Stance: Engineering Curricula Designed for Social Responsibility, *International Conference on Engineering Design ICED11*, Technical University of Denmark, Copenhagen, Denmark

The chapter examines the need for the engineering profession to address the major issues confronting global communities (in particular the 'other 90%') including lack of access to safe drinking water, adequate sanitation, clean and sustainable energy production, disease prevention, child mortality and low life expectancy. It is proposed that engineers engaged in product design and development require training in Socially Responsible Design if they are to contribute positively to the betterment of global societies.

Whilst most engineering courses develop awareness of ethical and sustainable design, the chapter questions whether awareness, as mandated by accreditation organisations (e.g. Engineers Australia), is sufficient. It is suggested that students need to develop acumen in social design through practical experience. The learning process can be improved by design projects that address real-world scenarios through the creative and human-centred application of engineering science and technology.

The chapter concludes with Case Study 3: *Developing social and sustainable design practice in Product Design Engineering*; a study of the ethical curriculum in the Swinburne PDE program.

4.2 Introduction

It is the role of engineering to provide the global community with socially responsible, ethical and sustainable design solutions. Engineering designers must contribute to the betterment of society through product service systems that facilitate sustainable development, enhance societal well-being and empower communities to be self determining. This will involve the engineering community in leadership roles in sustainable product design and development, responding to critical global issues, and engaging with emerging economies to deliver appropriate design solutions.

Engineers must extend their professional responsibilities from that of technical service providers (Beder 1999) and respond to critical societal and environmental issues with solutions that promote equity, equality and well-being for all. Societal engagement and even co-design will be necessary to create solutions that empower the community to determine their own destiny.

Social responsibility and sustainability is at the forefront of product design and development and consequently must be integrated throughout engineering education. Opportunities exist for well considered curricula to drive critical global agendas, determine attitudinal change and develop new aptitude in the next engineers.

As global designers, engineering graduates must be ethical and responsible, fully cognisant of the consequences of their professional activities, their potential for global societal contribution and their responsibilities to all stakeholders and communities. “Engineers have a critical role to play to help Australia and the world achieve sustainable development” (Desha et al. 2007, p. 1).

Design and engineering must service not just the needs of business, but also address the needs of society, particularly those communities in developing economies. It is imperative that all global communities have access to basic essential elements of life; clean drinking water, energy, sanitation, healthcare, education and the tools for self determination. Engineering competency must be balanced with social awareness, environmental sensitivity and cultural sensitivity.

“Technical virtuosity is often necessary, but never sufficient” (Webster 1996, from Beder 1998, p. x) The next generation of engineers will need to be responsible practitioners who are critically aware of the potential impact of their professional activities, cognisant of the contribution that engineering design can make to the quality of life in global communities, and imbued with the tools and design acumen to respond effectively (de Vere et al. 2009).

New engineering paradigms, such as product design engineering, can contribute to ethical engineering through curricula that integrate the principles of sustainable and socially responsible design throughout the learning journey, emphasising ‘design for need’, rather than market agendas, to achieve the requisite attitudinal change.

4.3 Examining the Problem

“There are professions more harmful than industrial design, but only a few of them.” (Papanek 1985, p. 1)

4.3.1 Market driven design

It is almost forty years since Papanek proposed that designers’ responsibilities should shift from market driven design towards social and environmental concerns. He advocated more responsible use of environmental resources and improved societal balance through new design agendas, declaring that “designers have become a dangerous breed” (Papanek 1985, p. 1). He was right to be concerned.

Product design, which emerged in the 20th century, “has historically been a contingent practice rather than one based on necessity” (Margolin 1998, p. 86) and is seen as having a fundamental role in the emergence of post-World War 2 consumerism. It has impacted buyer behaviour through planned, technical, functional or stylistic obsolescence, disruptive technology and through the use of ‘consumer engineering’ (adding value to increase desirability).

By the 1950s the USA was embracing a design-led consumer culture, leading economist Victor Lebow to state "Our enormously productive economy demands that we make consumption our way of life, that we convert the buying and use of goods into rituals, that we seek our spiritual satisfaction and our ego satisfaction in consumption. We need things consumed, burned up, worn out, replaced and discarded at an ever-increasing rate" (Lebow 1955, p. 3).

Design is still perceived as an industry intent on stimulating demand, regardless of the need of the consumer (Miles 1998), thus becoming an important social and economic organising force perpetuating consumerism as a way of life. “Designers operate in a world where the creation of wealth is a prime motivation…the role of design in contemporary society is essential in reproducing a socio-economic system that assumes limitless growth and a continual state of desire” (Whiteley 1993, p. 133).

Although the design process should involve more negotiation between the designer and the consumer, products are often imposed on a public which has little choice but to endure their social, environmental and economic impact. Miles (1998) believes “the values inherent in well designed goods are actually socially divisive and that design is actually symbolic of the socially divisive nature of consumption in general” (p. 49). He continues “design is not always liberating, creative or artistic, but often oppressive, conforming and dictatorial” (p. 49). Morelli agrees, “the traditional disabling (and product-centred) approach offers very few opportunities to improve the living conditions of underserved populations” (Morelli 2007, p. 19)

More recently the problem has gained in complexity. Global warming leading to climate change, diminishing natural resources and the impact of globalisation on emerging economies (especially global inequity, resource depletion and wealth disparity) has changed the landscape significantly, yet the agendas of the product design and development industry largely remain unchanged.

The sociology of consumption is problematic to designers working in social design. Thorpe (2010) states that designers are trained to add value to a business, “design is a key cog in the wheel of consumerism so it is no wonder that most designers have trouble conceiving their work in any other form than commerce and commercialism”

(p. 15). Indeed, it is worth noting that market-driven design practice, by catering to economically powerful groups with their consumerist design ideologies, works against the possibility of a social vision in design (Whiteley 1993; Nieusma 2004).

A review of these and other positions sees the emergence of several main issues:

- market incentives reinforce consumer-led design at the expense of the aspirations of social design
- when the solution is product dependent, the usefulness of the solution is dependent on the lifespan of the product
- solutions that are not co-designed or co-owned by users and community have little value in the socially responsible design arena
- globalisation has compounded the problem, escalating resource consumption
- designers are often inadequately trained or lack the corporate influence to be effective at socially responsible design

4.3.2 Globalisation

Globalisation has emerged as an invasive and persistent force driving world economies. It has the potential to increase worldwide economic prosperity as well as creating opportunity, enabling empowerment and enhancing well-being especially among developing nations. It is possible that globalisation will eventually lead to the enhancement of civil liberties, a higher standard of living and for free trade to result in a more efficient and equitable allocation of resources and rewards for all stakeholders (de Vere et al. 2010). However, so far globalisation has not realised its potential to create a more equitable and harmonious world, instead poorer countries have suffered many disadvantages including:

- the negative impact of western government subsidies and unfair trade agreements,
- the exploitation of impoverished workers (including children),
- environmental degradation and resource depletion, and
- the loss of local and regional contexts.

Globalisation has even impacted upon first world economies with 'off-shoring leading to skills loss and mass unemployment due to job relocation, diminishing societal potential. This impact is amplified by changing cultural patterns and an aging demographic (Morelli 2007). It is necessary for engineers and designers to be sensitive to the consequences of their activities, to understand the potential for a greater societal contribution and to be aware of their responsibilities to all global stakeholders, not just their clients and target market.

4.4 The Social Role of Product Design

"We cannot, *not* change the world" (socialdesignsite.com 2011)

4.4.1 Social design agendas

Since Papanek, there have been many proposals to advance a more socially responsible agenda for product design. Whereas Papanek pitted social designers against market driven economies, Margolin (2002) believes this limits the options of social designers, instead proposing that designers forge allegiances with professions related to health care, education and social work, and asks the question "what role can a designer play in a collaborative process of social intervention?" (p. 28).

Morelli (2003) takes up the issue with when he asks what the designers' role would be in a scenario where users empowered by a socially responsible action, are able to provide their own product and service solutions. He later suggests that "designers will no longer be proponents of a set of product and services, but rather the facilitators of a system of value co-production" (Morelli 2007, p. 18).

4.4.2 Engineering design as an agent for change

As a major contributor to new product development, engineering needs to develop a 'forward-looking' approach to the practice of socially responsible design. Product design has always attempted to 'change the world through design' however the motivation has not always been altruistic; instead focusing on increased sales, cheaper production and greater profit. However opportunities exist for engineering designers to contribute positively to the betterment of global societies, through product service systems that provide opportunities, guarantee well-being and empower communities, as shown below in Figure 4.1, the OWE-Equity triad.

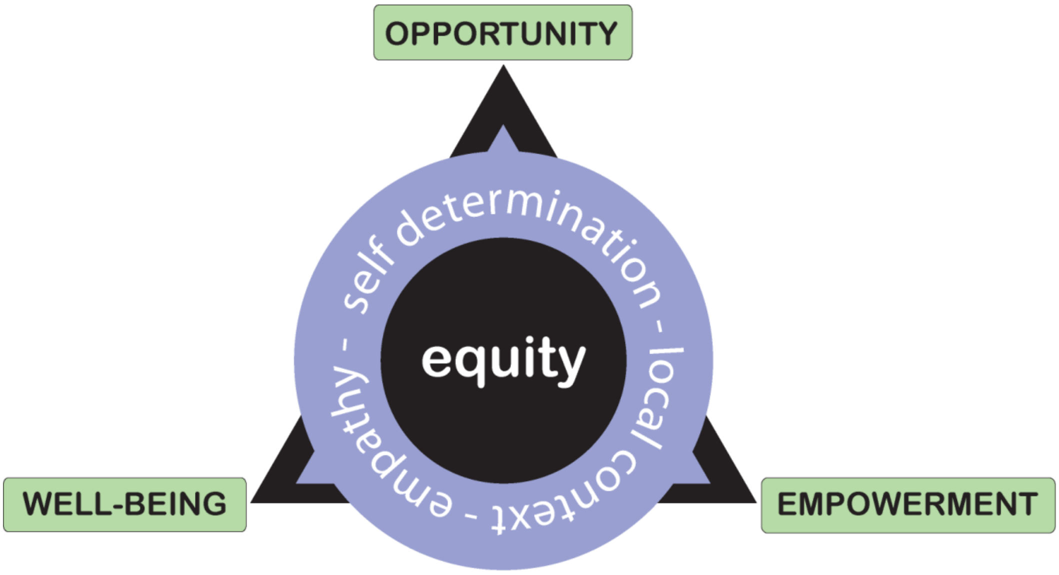

Figure 4.1: the OWE-Equity triad (Ian de Vere)

The OWE-Equity triad attempts to capture the three critical targets of socially responsible design; opportunity, well being and empowerment, represented as the three points of the triangle. These result from an empathetic process that is driven by an over-arching pursuit of societal equity within a local context framework, and providing the tools for self-determination. This model is a useful platform for teaching social responsibility to engineers.

The OWE-equity triad articulates the role of socially responsible design, which is:

- to provide opportunities for fair, sustainable and appropriate development,
- to enhance the social and collective capability of a community to develop its own solution,
- to enhance societal well-being through an agenda of equity, equality, and empathy,
- to empower communities to be self determining,
- to empower individuals to contribute positively, and
- to engage with understanding in a local context, to provide local solutions

4.4.3 Social engineering

"The future engineer will become the manager of designers of sustainable technology and therefore must also be able to address social issues. An academic engineer should also be trained as a social engineer" (Mulder 2004, p. 282).

Quality of life for those in developing nations is dependent on responsible product design decisions, and particularly the practice of 'design for need'. Engineers and designers must ensure that in their professional practice they:

- address the impact of their design and manufacturing on other communities,
- respond to critical societal and environmental issues (e.g. climate change, water, sanitation),
- develop renewable energy production systems,
- engage with communities to develop self sufficient and sustainable systems,
- involve the local community in the problem framing and design processes,
- respect cultural diversity and traditional values and ways of life,
- seek to achieve solutions that promote equity, equality and well-being,
- extend their professional responsibilities (from that of service provider).

To prepare engineers for these new societal roles and responsibilities, engineering curricula must incorporate thorough training in socially responsible design practice. Whilst it is critical that curriculum maintains engineering and scientific rigour, it must evolve from 'technical' training towards a more human-centred design 'practice' agenda. To achieve this, a strategic approach to social engineering must be implicit throughout engineering pedagogy.

4.5 Educating social design engineers

"Engineers are increasingly looked to for sustainable solutions yet find themselves less than adequately prepared to provide answers. Education is consistently identified as one of the key strategies for facilitating sustainable development; the required shift in the thinking, values and actions of individuals and institutions call for efforts to make sustainability concerns a central theme of all education" (Crofton 2000, p. 397).

4.5.1 The 'next' engineer

For many years, engineering regulatory bodies worldwide have identified the need for a new underlining principle for engineering practice. The 'Educating Engineers for a Changing Australia' report recognises the need for "a high level of understanding of the broad human, economic and environmental consequences of the professional tasks engineers have to face today" (Engineers Australia 1996, p. 22).

"It is clear that engineering must go beyond pure technology...and address matters that are imbedded in the social and economic fabric of society." (Akay 2003, p. 146) and that "engineering education needs to encourage engineers to appreciate the social, economic, political and environmental effects of the technologies they develop" (Johnston 1998). Unfortunately, Crofton's research has revealed that "engineers' knowledge, skills and/or practices for sustainable development are deficient or problematic....as a result engineers' ability to contribute to sustainable development effectively is compromised" (Crofton 2000, p. 397).

Clearly the engineering profession is at a defining moment. Engineering design must re-orientate from market-driven product development towards more systematic solutions. Engineering science must be balanced by new engineering considerations; human-centred design, universal design, participatory design and co-design/co-production will be required to achieve an appropriate design agenda.

As identified in Chapter One, it is imperative that engineering curricula addresses a broad social context of understanding, such as the mandatory generic graduate attributes set by Engineers Australia. These include understanding of the social, cultural, global and environmental responsibilities of the professional engineer, understanding of the principles of sustainable design and development and understanding of, and commitment to, professional and ethical responsibilities.

This will require significant curriculum revision and will need to be driven by regulatory organisations through course accreditation processes, if the 'next engineers' are to be thoroughly prepared for the challenges that they will face during their professional careers. Barry Grear, former president of Engineers Australia and the World Federation of Engineering Organisations (WFEO) asks "What aspirational role will engineers play in that radically transformed world?" (Grear 2006).

Reviews of engineering curricula reveal that many engineering graduates (whilst cognisant of the basic concerns) lack training and practical experience in socially responsible and sustainable design, and do not fully understand the potential environmental, social, cultural and economic impacts of their practice.

"The competency standards set out by Engineers Australia demonstrates that an understanding of sustainable engineering practice is expected of engineers emerging from high education institutions. What is needed now is for a curriculum transformation to engineering education for sustainable development" (Desha et al. 2007, p. 13). The next generation of engineering graduates will require more than the 'understanding' mandated by regulatory bodies; they will need an embedded ethical philosophy, design acumen and engagement experience to lead effective and appropriate local solutions that empower the user and their community.

4.5.2 Sustainability and Social Responsibility

"Design needs to serve not just the needs of business, but to also treat society and the environment as clients too" (Fuad-Luke 2007, p. 28).

Sustainable design addresses the 'triple bottom line', a reporting framework that considers ecological and social aspects, in addition to the traditional financial measures. These goals demand that corporate responsibility be to all *stakeholders,* not just shareholders. Consequently anyone who is influenced or affected, either directly or indirectly, must be considered.

We are now almost at the end of the United Nations 'Decade of Education in Sustainable Development' (2005-2014), a global initiative that aims to create a more sustainable future in terms of environmental integrity, economic viability and a just society for present and future generations. Whilst there is evidence that sustainable development has already been incorporated in engineering education in many institutions (Desha et al. 2007), it is difficult to find examples of focussed training in sustainable design tools and socially responsible design practice in most mechanical engineering courses.

Yet it is critical that all engineering curricula address ethical behaviour, social responsibility and sustainability. The next generation of engineering graduates must assume a leadership role in addressing the inevitable challenges in product design and manufacturing. They will need to deal with alternate energy, finite resources, regulatory carbon emission controls, emerging technologies and fluctuations in consumer behaviour and expectation. However, as graduates or junior employees lacking the corporate influence to be effective, they may struggle to implement change. Fortunately, the rigidity of *existing* workplace environments is evolving as an emerging ethical consciousness gains currency in markets, and new business opportunities develop for sustainable and equitable practice.

The biggest challenge to be faced by the next generation of engineers will be addressing the needs and aspirations of those who are not part of the first world consumer society; those who currently lack the basic elements that contribute to a healthy, safe and equitable lifestyle.

The issues confronting these global communities are well known, but are no less devastating when reiterated. At present:

- 1.1 billion people (out of 6.9 billion) lack access to clean, safe drinking water, (UNICEF 2006)
- 2.6 billion lack basic sanitation, resulting in 1.8 million annual child deaths from diarrhoea,
- 1.6 billion people, a quarter of humanity, live without electricity,
- up to 11 million children die each year due to the resultant conditions of poverty and debt,
- at least 80% of humanity lives on less than $10 a day,
- more than 1 million people die annually from malaria, mostly young children
- HIV/AIDS accounted for 1 million deaths in 2009,
- 963 million people suffer from chronic malnutrition, and
- the wealthiest 20% account for 76.6% of consumption, the poorest 20% consume just 1.5%

Many global societies lack the necessary resources for wellbeing, healthcare and education and are thus denied the tools for self-determination. Communities are in desperate need of solutions to sustainable energy production, sanitation, water supply, disease prevention, shelter, clean and efficient cooking, communication, and need permanent alternatives to ongoing humanitarian aid.

As those with the ability to apply technological innovation to user-centred product outcomes, it will be the responsibility of the designer/engineer to addresses these issues, through ethical practice and appropriate design innovation. These substantial and complex problems will need holistic solutions, solutions that are not just product-focussed, but people-focussed, locally/regionally focussed and co-designed. These socially responsible design solutions must "not only fulfil a specific individual need, but also enhance the social and collective capacity of a community to develop its own solution" (Morelli 2003, p. 8).

It is estimated that 80 percent of all product-related environmental impacts are determined during the design stage, whether through material specification, manufacturing processes, transport or packaging requirements, or resource consumption. Consequently, product design teams must not only be conversant with the potential negative impact of their design decisions from environmental, social, cultural and economic aspects, but be sufficiently skilled to navigate these difficult decision-making processes to achieve appropriate, sustainable product solutions.

But simply developing 'lower impact' products is not sufficient if they are still pander to the material and consumption needs of market driven economies. Opportunities exist for engineers to make a positive contribution to the well-being of global communities, specifically in water supply, energy production, sanitation, heating and cooking and healthcare. One example of a successful product contribution is 'LifeStraw,' a portable water purification device (refer http://www.vestergaard-frandsen.com/lifestraw), that for a relatively small cost, addresses the immediate need for safe drinking water. This product has made a positive design contribution to the UN's Millennium Development Goal (United Nations 2006) of improved water sources and reduction in infant mortality.

Appropriate design, fair trade initiatives, reduced ecological footprints and true accountability must be paramount if we are to reduce the negative impact of product design and manufacturing. The next generation of engineers will need enhanced skills and knowledge to address these critical societal, environmental and economic issues. Engineering curricula must prepare graduates though targeted educational programs that address sustainable and socially responsible design theory and application.

4.5.3 Human-centred and culturally sensitive

"To better serve humanity, engineers must at least attempt to understand the human condition in all its complexity" (Engineers Australia 1996). In accordance with course accreditation guidelines, it is vital that the 'next' engineers are truly human-centred in their design practice, understanding the requirements, roles and community status of they interact with, and respecting differing nuances of behaviour and expectation.

Social research, when combined with community engagement, facilitates significant cultural understanding and sensitivity to the value systems of differing communities (de Vere et al. 2009). Engineering students must learn the value and the tools to conduct thorough human-centred design research into the user, the culture and the environment. The traditional 'what, who, why, how, when and where' line of inquiry, should now be supplemented with new lines of inquiry based on appropriate technology guidelines.

4.5.4 Challenges for designers and engineers

Socially responsible design (SRD) has achieved varied success, due in part to the diversity of the approach. There are two typical approaches. One approach is the design of products or systems that are locally manufacturable and owned and maintained by the community. The other less-beneficial approach is the 'band aid' or 'parachute' solutions that may alleviate immediate concerns, but maintain dependency on first world manufacturing and supply chains.

The most suitable design solutions:

- integrate local existing skills and facilitate new skill training,
- utilise renewable local resources, and
- are empowering for the community.

The challenge for 'first world' designers and engineers is to let go of many of the inherent drivers or values of the market-driven design process. Product designers are typically 'value-adders' who enhance market value through improvements in usability, aesthetics, user experience and cost reduction and margin increases. These are critical issues for those tasked with improving market share, but the process of value-adding becomes redundant in a functionality-driven SRD solution, where survival, health, well being and affordability are the principle determinates (Melles et al. 2011).

The most advantageous and successful SRD projects use the co-design or participatory design approach where the design outcome is co-owned by the user and community. This necessitates that the designer relinquish personal control and 'ownership' of the design. However design engineers are typically remote from the user communities and this can result in design solutions that lack the essential local context necessary to be effective. In fact, inappropriate solutions can be detrimental to the advancement of the local communities, by increasing dependency, whether financial, social or technical, thus denying communities the tools for self-sufficiency and self-determination.

The solution is not necessarily technology driven, but rather a product or system that utilises appropriate local materials, skills and processes and can be easily maintained, replicated, developed or adapted to meet future needs.

4.5.5 Key SRD issues

Besides a fundamental adjustment of values and expectations for the designer engaged in socially responsible design, there are other significant concerns that impact on the success of the design solution, including increased dependency, remote solutions (lacking local context), and technology driven solutions.

Increased external dependency can result from inappropriate design solutions, technically complex products and non-local/regional solutions and is a likely to occur where participatory design is not involved. The dependency of a community can be based on financial, technical, material, manufacturing and supply or social factors, and is contrary to one of the principle aims of SRD, the successful empowerment of the community (Melles et al. 2011).

Remote solutions**,** those lacking local contexts, can result from designers who are physically remote from the communities and environments that they are seeking to assist. As a result, their design solutions can lack the local 'context' necessary for viability and longevity. The most successful socially responsible designs typically emerge from co-design processes with extensive community engagement. It is critical that the resultant design solution utilises local or regional materials, craftsmanship and expertise, facilities new skills and knowledge acquisition, and empowers the user and community to 'own' the solution. Solutions that increase reliance on 'first world' manufacturing and supply chains increase financial dependency, denying communities opportunities to achieve self-determination.

Technology driven solutions are a typical response from designers trained to be technology dependent who eagerly embrace new materials and complexity in a market-driven model, often without consideration of the cost, maintenance or accessibility of such products for those in developing nations. If a product is unable to be locally produced or maintained, then the solution creates technological and financial dependency. Products with high levels of complexity, especially those with electronic circuitry, whilst providing an immediate short-term solution, in the long term are detrimental. "Innovative technology can be disruptive and trigger a backlash from incumbents" (Kraemer et al. 2009, p. 72). The solution is to use 'appropriate' locally accessible technologies that are easily replicated, maintained, improved and adapted to meet changing needs, e.g. Papenek's radio.

4.5.6 A check list for socially responsible design

The success or effectiveness of socially responsible design can be measured against the criteria outlined in Figure 4.2. The major criteria of need, suitability and affordability, potential for advancement, local control and empowerment must be addressed if the product or service system is to be not only successful. However products need to offer more than just short-term benefits, they must have longevity not just as an artefact, but as an instrument of change and community empowerment.

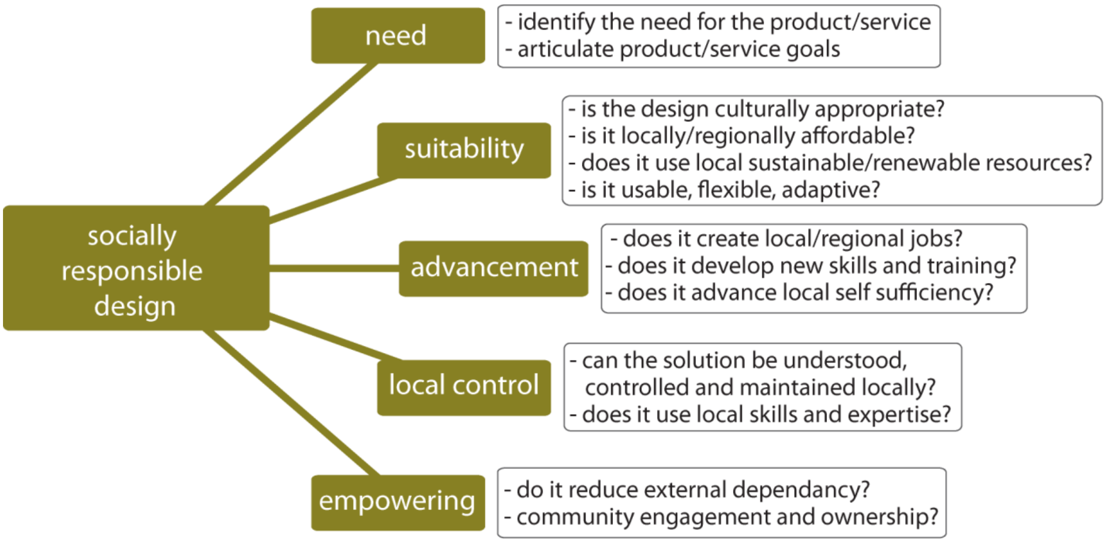

Figure 4.2: a checklist for socially responsible design (Ian de Vere)

4.5.7 Effective SRD in action

A good example of this approach is the Rural Integrated Development Service in Nepal (RIDS-Nepal 2006). Amongst their many initiatives is the development of a smokeless metal stove for remote communities who have traditionally used open fires for cooking, lighting and heating, resulting in widespread eye and respiratory problems, lung cancer, tuberculosis, pneumonia, low life expectancy and extensive deforestation. The design of the stove, besides addressing the key criteria of indoor air pollution and resultant health, also achieves cleaner and safer interior environments, improved cooking, reduces the consumption of limited firewood resources by 50 percent and heats water for cooking, cleaning and hygiene.

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Figure 4.3: The RIDS – Nepal smokeless metal stove in situ (left) and in local production (right) (image source: RIDS-Nepal)

Besides achieving all of its performance related targets, the product service systems agenda is also well considered. The stoves are made in the business centre of Nepalgunj, directly below the mountain villages, by local people trained with new skills of sheet metal fabrication and welding. In this model, the urban workers with training become skilled and free of external dependence, whilst the end user receives an affordable and effective solution that can be assembled, installed and maintained using local expertise. The holistic community development project, 'Family of 4' installs a clean water supply, a pit latrine, a smokeless stove, and indoor lighting, with a 50 percent subsidy to Nepalese families.

These projects along with many others, including the "Light up the World" initiative, are led by engineer Alex Zahnd, who works directly and collaboratively with communities to realise viable resolution to local problems. These successful engineering-led solutions represent best practice in socially responsible design.

In these solutions the cultural context of the solution is that of the user and their community, not the designer's projected personal values. Designers and engineers should not view their role as providers of a product outcome, but rather view the customer as a resource, not just an end-user. In this sense, design becomes a facilitating tool with power of suggestion, resulting in community enablement and lifelong solutions (Morelli 2007).

4.5.8 Comparison of SRD approaches

This is not to say that quick and immediate solutions or products are not necessary, rather that the long-term interests of a community are best served by permanent infrastructure, rather than short-term externally produced products. For example the LifeStraw, a personal water purification device, filters contaminated water through iodine, mesh and carbon filters, removing 99.9% of waterborne bacteria and protozoan parasites.

However this product will only supply enough water for the annual needs of a single person, and has been criticised for diverting attention from much needed long-term water infrastructure. Whilst highly valuable in fighting water-borne disease, it is a ‘parachute’ product dependent which cannot be produced locally, as such it promotes dependency. By contrast, establishing a reliable source of clean water in villages is a more effective long-term solution. Permanent infrastructure projects such as Slow Sand Water Filters are almost as capable as the LifeStraw purifiers, but rely on readily available materials and simple local construction. Although these water purification systems are not portable nor aesthetically pleasing, they provide communities with local control of the future water supply, without dependence on imported technology (Melles et al. 2011).

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Figure 4.4: left- LifeStraw personal water purification product (image source Design for the Other 90%), right - Nepalese Slow Sand Water Filter (image source RIDS –Nepal)

4.5.9 A process of engagement

Engineers need to be taught how to engage with communities to understand the problem and co-develop a solution. In response, the author has developed the following representation of an approach for human centred design and appropriate technology practice.

Figure 4.5: a process of engagement for socially responsible design (Ian de Vere)

This 'engagement' approach is dependent on the design engineers actively engaging with the local community, listening to their problems, using observation and reflection to learn before engaging with the community to co-create a solution that empowers the community to determine their own destiny.

4.6 New learning in engineering

There is an increasing focus on new roles for engineering; roles where the 'soft' or non-technical issues of engineering practice are given more emphasis. "A better response lies in changing the scope and significance of what engineering is, and more important, who engineers are – namely, adept people who serve humanity through the application not simply of math and science, but of a wide array of disciplines" (Grasso et al. 2007, p. 14). These sentiments are widely supported. "Clearly, engineers must complement their technical and analytical capabilities with a broad understanding of so-called "soft" issues that are nontechnical. Experience has shown that social, environmental, economic, cultural, and ethical aspects of a project are often more important than the technical aspects" (Amadei 2013, p. 25).

This aspiration for the engineering profession establishes a critical agenda for engineering as a profession. As a result, engineering curricula will need revision to ensure that it prepares engineering graduates for their new roles and responsibilities.
"Social issues are easily neglected in engineering. A cultural change in engineering education is needed" (Mulder 2004).

4.6.1 Curriculum for sustainability

"Within university communities, in particular, we must create an intellectual environment where students can develop an awareness of the impact of emerging technologies, an appreciation of engineering as an integral process of societal change, and an acceptance of responsibility for civilization's progress" (Bordogna et al. 1993).

Engineers need to play a central leadership role in developing appropriate technical solutions. The major challenge is to educate a new generation of engineers who are capable of problem framing and working in multi-disciplinary environments. Whilst engineers occupy key roles in innovation, their practice is often limited by the current discourse of the profession, which emphasises problem solving, but fails to involve the community in framing the problems (Johnston 1998).

"Engineering education has to prepare young engineers to accept sustainability as a basic design requirement for the development of products and processes...(and) provide the older generation of engineers with a reformation process in order to adjust to a technology that is in harmony with the environment" (Johnston 1998, p. 90). It is not sufficient to merely provide tacit knowledge or awareness. Deep-centred understanding and empathy is required. This can be achieved by integrating sustainable and socially responsible design at all stages throughout the learning journey, and providing opportunities for experience with real world design projects.
In the following examples, Product Design Engineering students from Brunel University and Glasgow School of Art have provided differing approaches to

sustainable design. In Figure 4.6 the Brunel student has developed a modular, hydroponic window farm designed to encourage urban dwellers to reconnect with the source of their food by nurturing their own herbs, fruit and vegetables.

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Figure 4.6: Hydroponic herb and vegetable garden system for apartment dwellers
(image source: Made in Brunel)

In the following student design (Figure 4.7), a final year student from Glasgow School of Art has developed a sustainable energy system for domestic applications that uses microbial waste treatment to develop biogas for heating and cooking.

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Figure 4.7: 'Composting with benefits' – a biogas generator that utilises anaerobic digestion
(image source: Glasgow School of Art product design engineering final year student

4.6.2 Ethical design in PDE curricula

All of the surveyed global PDE curricula integrate sustainability and socially responsible design throughout the design studio subjects of the program.

Social responsibility was identified in the 2010 Curriculum Benchmarking Survey (see Chapter Two) as a critical curriculum agenda in 71 percent of programs whilst sustainability was considered critical in 59 percent of PDE programs. This was reflected in expected graduate attributed for product design engineers with 77 percent of programs expecting graduates to be responsible practitioners.

By adopting a human-centred and socially responsible design philosophy that incorporates appropriate technology principles, the product design engineering programs aim to deliver 'social' engineers into the workplace. Real world 'design for need' projects are utilised to encourage students to shift their focus from the allure of consumer products and unsustainable practice, towards design solutions that respond to a community's immediate existence, subsistence and cultural needs, such solutions may be system or services based, rather than product focused. "Socially-responsible design should therefore aim at generating solutions based on a mix of products and services with high cultural and social significance" (Morelli 2003, p. 8).

It is not always possible in an educational context for students to fully engage with their targeted communities, nor to fully understand the context and cultural environment in which they are operating. Whilst working collaboratively with humanitarian aid organisations provides an insight which develops student empathy, students may lack a deeper understanding of the critical cultural, environmental and societal issues that must be addressed.

However, the outcome of social design projects is the development of a human-centred focus and an ethical approach to design; beneficial attributes for these 'next' engineers. As noted by Boks and Diehl "communicating sustainability criteria is most successful when done in an integrative setting, mimicking real life design problems" (Boks et al. 2006, p. 165).

4.6.3 Learning outcomes

Whilst collaborative projects aim to achieve successful outcomes, it is difficult for students located at a distance from their target communities to achieve effective and appropriate design solutions, or to realise product production. Of far greater impact are the learning journey and the resultant attitudinal change. Graduates demonstrate a philosophy of sustainable and socially responsible design, not just the professional skills and knowledge expected by industry. Additionally, graduates become aware of the power of design to drive community empowerment, enhance well-being and improve lifestyles.

It is expected that this awareness will impact graduates' professional behaviour. Even if not directly engaged in social design, it is hoped that they will be critically aware of their potential impact on environments and communities and will utilise social and ethical considerations in all spheres of activity.

Whilst it is understood that many graduates will not be in a position to lead reform in product design and development early in their careers, it is the responsibility of educators to prepare graduates for the many challenges they will face professionally throughout their careers. It is not sufficient to simply instil desirable graduate skills; the next generation of engineers must possess the aptitude, knowledge and commitment to deal with changing circumstances and demands. Engineering designers need to be thoroughly prepared for leadership in ethical design processes.

The experience gained from engagement with industry and community to address critical social needs is invaluable. It demonstrates the power of design innovation to improve quality of life, and to assist those in greater need. In the student design below (Figure 4.8) the student cooperated with Engineers without Borders to address the needs of communities in remote areas of India. The resultant design provides an efficient and non-polluting cooking stove, with the capacity to purify water (by boiling) to combat waterborne disease. Working collaboratively on a 'live' project with humanitarian workers provided a unique learning opportunity.

Figure 4.8: 'Rocket' stove with inbuilt water purifier developed by final year Swinburne PDE student in conjunction with Engineers without Borders (image source final year student).

4.7 Conclusion

"The engineering profession must be accountable not only to the needs of business but to the communities and environments that are affected by its professional activities" (de Vere et al. 2009, p. 537).

"Famine, drought, disease, pollution, violence, ignorance – such problems are systemic and so seemingly intractable that social planners have described them as 'wicked'. Designers, who traditionally operate at the point where object (or communication) meets user, lack the training for this grinding realm of competing interests and entrenched behaviours – an arena where expertise includes the ability to influence policy through delicate negotiations" (Lasky 2010, p. 1).

Design engineers will continue to be challenged to prevent further environmental degradation, to alleviate the impact (and causes) of climate change and ensure that future design solutions are sustainable, appropriate, and empowering. This will require a paradigm shift in the design, engineering and manufacturing sectors, driving cultural change in consumer behaviour and promoting a new awareness and consciousness in product design and development.

This must be led by educators, through curricula that integrates and values the principles of sustainable and socially responsible design at all levels of the learning journey. Whilst most engineering courses cover sustainability and ethical design in some form, theory-based subjects do not provide the learning experience afforded by real world design projects, consequently graduate engineers may not have the skills, knowledge and motivation to participate in social design.

The next generation of engineers must be imbued with awareness, understanding and the tools to facilitate change; this will require a new ethical philosophy in both student and lecturer. The social and environmental impact of products must be addressed not just at the design stage, but at an educational level. The following case study describes how this may occur, by describing the integration of ethical curriculum into a product design engineering program.

Case Study 3: Developing social and sustainable design practice in Product Design Engineering

Introduction

This case study examines the development of sustainable design and socially responsible design practice within a Product Design Engineering curriculum, in this instance the program from Swinburne University of Technology. It examines a systematic teaching program that imbeds critical engineering agendas throughout the learning journey. Swinburne's PDE curriculum provides opportunity not just for discussion and resultant awareness, but for the building of expertise and experience in the resolution of complex global issues.

Integrated ethical design

The Swinburne PDE curriculum integrates sustainability and socially responsible design throughout the design studio subjects of the program. The curriculum is structured to ensure student awareness and understanding of socially responsible and sustainable design, and to develop responsible and appropriate practice.

The principles of sustainability are introduced in the first year design studios. This is followed in the first semester of second year, by training in the tools of sustainable design, e.g. Life Cycle Analysis, Cradle to Cradle Design (McDonough et al. 2002) and Luttropp's Ten Golden Rules of EcoDesign (Luttropp et al. 2006). From this point onwards, students are expected to utilise sustainable design methodology in all studio projects. Socially responsible design, specifically designing for the needs of disadvantaged communities, is the focus of third and final year design studios.

Sustainability

In the second year, students are introduced to the tools of sustainable design, and eco-design tools such as Life Cycle Analysis (LCA) which measure the impact of a product throughout material sourcing, manufacture, usage and end of life disposal. The initial design project requires students to understand the implications of electronic manufacture and resultant 'e-waste' issues, and then develop environmentally sustainable communication devices that meet the Waste Electrical and Electronic Equipment (WEEE) directive. By employing environmental design tools throughout the project, eco-design is systematically integrated in the student projects. Moreover, the 'raison d'etre' of the device is also questioned; devices that add to mass consumerism without addressing a societal need are discouraged. Final design outcomes must be validated through an "end of life" scenario and life cycle analysis and are assessed against eco-design principles (Melles et al. 2010).

As students progress through the curriculum, they are expected to apply sustainable design principles to all their design and engineering outcomes. Students are required to embrace a 'cradle-to-cradle' philosophy (McDonough et al. 2002), demonstrating aptitude and understanding of sustainability with appropriate low-impact material and manufacturing process selection, with consideration of energy usage, embedded energy, resource renewability and 'end of life' scenario. The Design for Sustainability (D4S) approach is based on Triple Bottom Line (TBL) consideration of social, economic and environmental performance (Melles et al. 2010). Students are required to take a life cycle view of a product, including design for disassembly (DfD) with design solutions being analysed using life-cycle analysis tools e.g. Eco-Indicator, GreenFly and Solidworks' Sustainability Xpress.

The Australian Universities Community Engagement Alliance states that "exposure to curricula that are informed by real world problems and solutions promises many benefits for students and their communities" (AUCEA 2006) a position supported by Boks and Deihl (2006) who found that "communicating sustainability criteria is most successful when done in an integrative setting, mimicking real life design problems" (p. 165). Accordingly, Swinburne PDE students are regularly presented with real world scenarios, often through engagement with communities and aid agencies.

Developing sustainable design practice (2nd year design studio)

The introductory 'Sustainable Design' subject introduces the principles of sustainable design (SD) through an eco-design project. Students are tasked with responsible design of an electronic product that is 'inspirational' not aspirational, exploring the impact of 'e-waste' and using ethical and eco-design means to develop 'low impact' communication devices. Design outcomes are informed by the early inclusion of sustainable design agendas. 'Band Aid' solutions are not acceptable, neither are designs without a 'genuine need'. Designs are validated against a range of critical eco-design criteria, such as life cycle analysis and adherence to Luttrop's Ten Golden Rules of EcoDesign (Luttropp et al. 2006), a checklist designed to help designers integrate environmental design issues at early concept phases.

Sustainable design: student project example 1

The hand-powered Remittance Banking Device was designed specifically for the low socio-economic regional populations of Africa and other developing nations. Working on mobile phone operating principles, it is tailored to act as a portable banking device, suitable for people living in remote (unpowered) areas and dislocated from banking infrastructure. The student proposal (see Figure Cs3.1) included a cradle-to-cradle approach, the use of recyclable and recycled or organic plastic polymers, with electronics compliant with the Reduction of Hazardous Materials Directive (RoHS). The use of a super-capacitor to store the hand-generated energy negates the need for environmentally damaging batteries.

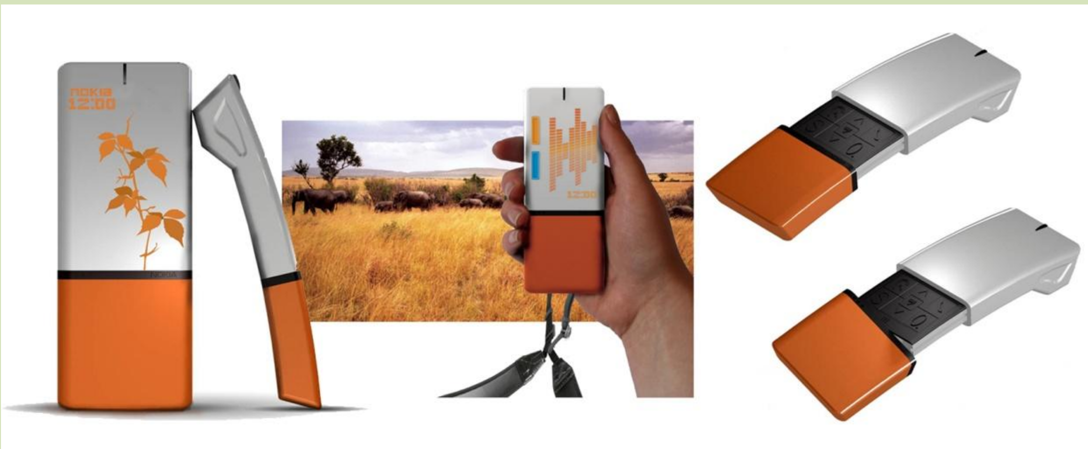


Figure Cs3.1: hand powered banking communicator for remote communities
(Image source: student generated designs- 2nd year Product Design Engineering group project)

Sustainable design: student project example 2

The Life Band was conceived as an emergency communication device that could be worn as a wrist band and could then be unclasped to interface via a USB connection with any computer system. This low-impact design proposed the use of flexible organic light-emitting diode (OLED) technology to simplify product manufacturing and reduce both costs and power consumption.

Figure Cs3.2: life band' emergency communication device
(Image source: student generated designs- 2nd year Product Design Engineering group project)

Sustainable electronics

The projects described above respond to social needs, with students taught that the proliferation of unnecessary consumer products contributes significantly to over-consumption, pollution and resource depletion.

However, the primary outcome of the design project was dealing with the complex issues surrounding the design and specification of 'sustainable' electronic products. This type of product typically has substantial environmental impact due to manufacture from oil-based polymers, inclusion of hazardous electronics materials, high energy consumption, short-life spans and poor end of life planning.

Nonetheless an effective ‘cradle-to-cradle’ design approach can deliver a significant reduction in impact which students’ measure using life cycle analysis. Designing electronic products to meet the Waste Electrical and Electronic Equipment Directive (WEEE Directive) and the RoHS, with careful consideration of initial material selection and design for recycling of raw materials from end-of-life electronics, is the most effective solution to the growing problem of e-waste. Most electronic devices contain a range of materials (including metals) that can be recovered during dismantling and recycling. Designing for reuse conserves intact natural resources, reduces pollution caused by hazardous material disposal and reduces the amount of greenhouse gas emissions caused by the manufacture of electronic products.

These projects contribute significantly to student awareness and learning with both the motivation and the tools for sustainable design practice acquired during the semester. Once sustainable design is imbedded in student processes, all subsequent design projects require a sustainable design outcome, validated using appropriate eco-design measuring tools. This is the beginning of an educational journey that prepares the Product Design Engineers for the sustainable design expectations of new product development industries.

Social responsibility

In the third year of the program, the teaching focus switches to socially responsible design, a design process that contributes to improving human well-being. Working collaboratively with humanitarian aid agencies, students address specific scenarios in need of design intervention. These are often active projects concerning disaster relief, health care provision, communication and development of remote community infrastructure. These projects “encourage human-centred research examining the contribution of the design engineer, facilitate collaborative working with communities to realise appropriate sustainable solutions, develop sensitivity to cultural issues and barriers, and demonstrate the importance of appropriate technologies” (de Vere et al. 2009, p. 535).

Projects focus on the utilisation of local materials, technologies and expertise to achieve viable and appropriate solutions; this can be difficult for students expecting to deliver high quality commercially-oriented product designs. However the focus is directed towards 'appropriate' design solutions which combine innovative application of engineering theory with the capabilities and resources of the targeted communities. "These products all address "triple-bottom-line" accounting criteria, and serve to foster a responsible, appropriate, and sustainable approach to product design" (Melles et al. 2010).

Social responsibility and community engagement (3rd year design studio)

Engagment with NGO aid organisations provides students the opportunity to work closely with aid workers, gaining valuable insights into the social, cultural, environmental, fiscal and technical issues that impact on successful design outcomes and implementation of appropriate solutions.

Working collaboratively with a humanitarian aid agency over several years has resulted on more than seventy student design solutions (for products and infrastructure) addressing real world scenarios, often from active humanitarian projects. The NGO partner has supplied several scenarios from their global humanitarian relief activities, for example:

- low birth outcomes in Makwanpur, Nepal,
- child survival in Uttar Pradesh, India,
- reducing child and maternal mortality rates in Uganda,
- health service reconstruction in Banda Ache, Indonesia (post tsunami), and
- Kala Azar (Leishmaniasis) disease prevention in Somalia.

These scenarios are by definition 'wicked problems' that required firstly problem framing, then human-centred design processes including the use of Empathy Maps (to identify needs and insights) and Composite Character descriptions (to personalise the students' perception of the user). Project outcomes analyse the social, environmental and economic implications and must provide not only functional design solutions, but must utilise local skills and materials, provide regional economic benefits, and empower the community to own the solution.

In addition to significant learning, many innovative and appropriate design solutions have been realised, including the following product and infrastructure designs:

- honey extractor to provide nutrition for Ugandan children,
- locally produced ceramic autoclave (incorporating traditional materials and craftsmanship) – refer to Figure Cs3.3,
- bamboo pulp fibre portable water filter to address water quality in Papua New Guinea - refer to Figure Cs3.4,
- portable transpiration greenhouse to generate clean water ,
- solar powered food drying/preserving system,
- portable vaccine and syringe transportation unit, and
- aerobic toilet for disaster relief

Design for Care: student project example 1

The ceramic autoclave (Figure Cs3.3) addresses the issues of infant mortality in Nepal particularly during or after childbirth. 36 percent of neo-natal deaths are due to infection caused by lack of access to medical facilities and sterilisation processes.

The autoclave provides the means to sterilise birthing equipment with a ceramic pot system that can be placed directly into a domestic fireplace. Pot and lid components are manufactured from readily available local clay moulded in a steel template to ensure component standardisation and compatibility to provide the necessary sealing. This student design represents a good grasp of SRD; an affordable and mostly locally sourced product that is easy to operate and maintain, and culturally appropriate.

Figure Cs3.3: Socially responsible design outcome - ceramic autoclave utilising local materials (Image source: student generated designs- 3rd year Product Design Engineering group project)

Design for Care: student project example 2

The bamboo pulp water filter and transporter (Figure Cs3.4) is an innovative solution to a water supply problem that is widespread in developing economies, particularly in rural and remote communities; that people must travel considerable distances to access water, which may not be suitable for drinking.

The water is stored within the wheel which facilitates ease of transport (without lifting) whilst the rotation actively filters the water through layers of bamboo pulp; this consumable sourced from a readily available local material in Papua New Guinea.

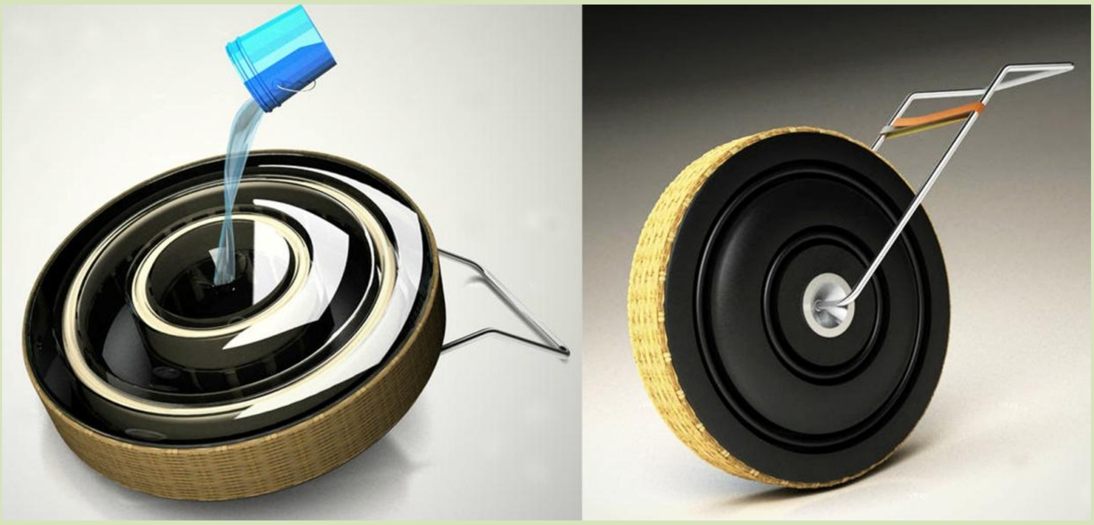


Figure Cs3.4: Socially responsible design outcome - bamboo pulp fibre portable water filter (image at left has covered removed to real internal structure) (Image source: student generated designs- 3rd year Product Design Engineering group project)

The benefits of such a design are:

- enhanced water quality leading to improved community health
- reduction in time occupied by water transportation, freeing up time for more productive activities (such as education, income generation, etc)
- reduced burden of responsibility on women in the community
- possible entrepreneurship opportunities in local filter production

Design constraints

As identified earlier, the use of local materials and craftsmanship can contribute to the empowerment of the community to 'own' the solution, without increasing their external dependence. It is not always appropriate to 'thrust' technology at a third world problem. Often a simple but effective solution will have greater longevity and community acceptance. It is critical that students learn to design for the local context without imposing 'first world consumer' product expectations onto the design process.

This is not to suggest that product solutions should be in any way unrefined or less well resolved, rather that SRD products must be 'appropriate' in that they are affordable, easily repaired and maintained, and empower the user community to understand and further develop the solution to gain independence from poverty and humanitarian aid. Affordability, functionality and a reduction in complexity are driving design constraints, although there is no reason for user-product interaction to be compromised.

Ethical design (4th year design studio)

The final year of the program sees students undertake ethical design projects on two levels. Firstly, the design studio project addresses societal and environmental issues associated with the Melbourne urban vernacular, in particular poor public transport, car dependence, and traffic congestion. In this group project, which responds to the Melbourne Transport Strategy (Currie 2005), students investigate options for personal commuter transportation, including public ownership bicycle schemes, shared-ownership vehicles that utilise low-carbon and closed-loop power sources, and alternative public transport solutions. Secondly, the final year capstone project requires students to research a social or environmental need and then collaborate with industry and community to develop an appropriate design solution.

2030 carbon neutral vehicle project (4th year)

In this project, students were challenged by an industry partner to develop a future commuter vehicle intended for shared ownership, which utilised a low carbon power source and considered recharging and collection infrastructure. Central to the project intent was the alleviation of urban problems caused by car dependency; traffic congestion, diminishing air quality, green house emissions and urban sprawl. Applied research examined commuter behaviour; the demands of vehicles on urban infrastructure and alternative power source technologies, and research findings were incorporated with a 'cradle-to-cradle' philosophy in the final designs. Project outcomes were well received by local government and facilitated sponsorship and future project involvement from Sustainability Victoria, a Government-established statutory authority whose objective is to facilitate environmental sustainability.

Figure Cs3.5:carbon neutral vehicles for shared public ownership
(Image source: student generated designs- final year Product Design Engineering group project)

The student project outcomes shown in Figure Cs3.5 are indicative of the creative and well-considered results from this project. The proposed vehicles display a unique and marketable identity, are designed specifically for short urban travel, usually for just two persons, and are highly manoeuvrable. Most importantly the designs utilise low-carbon footprint power supplies including compressed air motors, hydrogen fuel cells, electric motors, and closed-loop energy systems. The carbon footprint is defined not just from the vehicle's usage, but through the original energy generation. Therefore, electric cars deriving their power from non-renewable energy (the primary source of Melbourne electricity is derived from brown coal) are not considered appropriate solutions. In this regard the supporting infrastructure was also examined, with students required to propose alternative supporting infrastructure (e.g. solar and wind energy) to ensure their vehicles were independent of the existing power grid.

These designs are highly conceptual with student proposals considering a range of user behaviour and situational vernacular and designing unprecedented vehicular solutions to address future needs. Technology advancements as well as future commuter expectations were considered in design solutions that integrated life-cycle and cradle-to-cradle considerations from the outset (Melles et al. 2010).

Bicycle share scheme (4th year)

The "Ozcykler' project involved students studying the Melbourne vernacular, identifying commuter behaviour patterns, transport hubs and then developing a shared public bicycle scheme. The outcomes included the bicycle design plus system design and associated infrastructure (hiring and payment strategies and systems and collection hubs), integrated into the local urban environment. The project addressed the congestion of Melbourne urban areas through the development of an appropriate bicycle sharing system that facilitated short urban commutes, met compulsory helmet-wearing requirements, encouraged healthy lifestyles and provided a distinctive bicycle design for promotional purposes. The project relied on human-centred research, in particular behavioural observation and needs anticipation. The resultant product service systems have the potential to act as agents of change in the context of the Australian urban landscape and commuter behaviour.

Students developed designs fully resolved through the consideration of user-product interaction, ergonomics and anthropometrics, design for the public domain, functional mechanical design and service design.

Figures Cs3.6 (above) and Cs3.7 (below): shared bicycle scheme including payment hub, helmet dispensing bollard and bicycle locking rack. (Image source: final year Product Design Engineering)

Addressing local issues

Whilst engagement with international communities is enlightening (but difficult), there is also value from engaging students in local issues where the students can more easily connect with end users and understand the local vernacular. These ‘ local context’ projects, have provided opportunities for students to address urban issues and commuter behaviour, developing products and service systems that reflect sustainable and social design principles, aligned with strong contextual citing. These curriculum examples encompass the integration of the supporting infrastructure into the local urban environment.

By engaging students in local projects that are at once both easily accessible and understandable, students learn to interact with their community as responsible and sustainable designers, and gain awareness of their potential to contribute to societal improvement.

Addressing social needs (final year)

The culmination of the Swinburne PDE course is the final year self-initiated and self-directed 'capstone' project. Projects must address environmental, humanitarian, medical or sustainability agendas and represent innovative human-centred design and creative engineering. Extensive research is necessary to identify critical social needs that will inform the design process. Design outcomes must be socially responsible, sustainable and appropriate for the target user, community, culture and their environs. The project provides graduating students with the opportunity to express their fluency and competency in social design.

Students work closely with industry partners including humanitarian NGOs, technical facilitators, and design and manufacturing professionals to develop products that respond to a thoroughly researched 'social need' within local or global communities. Products outcomes typically address such issues as:

- the needs of the disabled or socio-economically disadvantaged,
- disaster relief,
- aging demographics,
- healthcare provision or palliative care,
- reducing environmental degradation or resource depletion,
- design against crime, and
- clean energy production.

Recent projects include wind and hydro-energy generators, an agricultural fertilisation/pesticide applicator that eliminates chemical spraying, a bio-ethanol generator, water purification, sanitation for disaster relief, mobility aids for the physically impaired, energy independent lighting, pest management, and an air purification system that utilise micro algae to transform CO^2 into oxygen.

Project outcomes are critically analysed against a range of criteria including Design for Environment (DfE) with Life Cycle Analysis (LCA), Failure Mode and Effects Analysis (FMEA), and Design for Assembly and Disassembly (DfAD).

Design addressing social needs: student project example 1

Working collaboratively with the Melbourne traffic police and a leading biomedical company with expertise in micro-fluidics and Raman spectroscopy, this final year student developed a roadside motorist drug-testing device that significantly improves the test system, enabling faster and more accurate testing. The outcome is indicative of socially responsible design, with a high level of consideration for users, strong contextual and societal understanding and potential to contribute to a safer society. The design (shown below in Figure Cs3.9) has significant product realisation potential, and illustrates the way that innovative design and emerging technology can be merged to prevent the occurrence of crime.

Figure Cs3.8: Design against crime - Roadside drug testing analysis unit for use by police (Image source: student design with industry partner- final year Product Design Engineering project)

This project outcome was fully resolved for manufacture, and utilises advanced micro-fluidics ‘lab-on-a-chip’ technology to analyse saliva samples collected on a disposable test strip. Whilst the outcome may appear from an external view to be an industrial design project, the realisation of this design incorporated significant engineering design (including fluid dynamics and micro fluidic system design), and engineering analysis including water-proofing, impact (drop) testing, using finite element analysis, and failure modes effects analysis (FMEA).

Design addressing social needs: student project example 2

The need for clean energy production is paramount in the eyes of the Product Design Engineering student cohort. This student design focuses on integrating an innovative vertical wind turbine into the existing power infrastructure, with turbines placed alongside major arterial roadways and mounted onto power poles.

Figure Cs3.9: Clean energy production – roadside wind turbines
(Image source: student design - final year Product Design Engineering project)

The vertical axis wind turbine design incorporates a number of helical aerofoils vertically mounted on a rotating shaft or framework, and is an evolution of both the Darrieus turbine design and the Gorlov helical turbine (GHT).With the helical design, the blades curve around the axis, more evenly distributing the aerofoil sections throughout the rotation cycle, so there is always an aerofoil at every possible wind angle. As a result the turbine generates a smoother torque curve and there is much less vibration and noise. The student's computational fluid dynamics (CFD) testing suggests good efficiency, plus the ability to evenly harvest wind from all directions in inconsistent conditions.

Design addressing social needs: student project example 3

Addressing the needs of changing demographics and an aging population is one of the primary challenges facing designers in the western world. This student worked with elderly support groups to realise a product outcome that performs as a walking frame, a seat and most importantly as a device that lowers to the ground to provide a kneeling platform and then hydraulically assists the user to return to their feet.

Figure Cs3.10: hydraulically assisted kneeling (and rising) aid for the elderly
(Image source: student design - final year Product Design Engineering project)

This project outcome represents simultaneous integration of engineering design and human-centred design processes. The hydraulic lifting assistance system is lightweight and well resolved and is designed to compensate for the elderly users lack of strength and mobility. The final design was supported by extensive social and user-centred research through direct engagement with relevant aged communities.

The three student design examples shown above represent three different facets of ethical design, in which the PDE students have gained experience during the course:

- design against crime (social design),
- alternate energy production (sustainable design), and
- design for need (socially responsible design).

Swinburne's commitment to sustainability and socially responsible design underpins the Product Design Engineering curricula. Students gain practical experience in all aspects of 'ethical design' from the basics of material selection, design for disassembly and responsible 'end-of-life' strategies, to collaborating closely with community groups to deliver appropriate social design solutions.

Successful curriculum implementation

Through humanitarian projects and commu nity engagement the Swinburne Product Design Engineering program aims to imbue students with an understanding of their societal role as the 'next' engineers. These efforts in curriculum development in these agendas have been acknowledged by industry and community, and recognised within the University, with the awarding of the:

- 2011 Swinburne Vice-Chancellor's Award for Sustainability in recognition of the successful integration of sustainability and socially responsible design concepts and practices into the Product Design Engineering curricula, and the

- 2010 Vice-Chancellor's Award for Community Engagement for development of a socially responsible design curriculum which engages students in real world projects, through collaboration with community groups and humanitarian aid agencies such as World Vision and Sangam, the Australia India design platform.

Conclusion

The examples of project work in this case study (produced by Product Design Engineering students at Swinburne University of Technology) show how students can simultaneously address environmental and social concerns with a high level of technical resolution and innovative application of engineering science.

"In these socially responsible projects, design is seen as the means to empower the user; the resultant functional product, when viewed in its system of use, from cradle to grave, must satisfy the objective of helping the user but in doing so must provide the community with some economic gain (monetary, education, health, etc.) with minimum environmental impact." (Melles et al. 2011)

Swinburne Product Design Engineering students are taught to develop products and product service systems that utilise eco-design tools, user-centred design processes and address the holistic needs of society. As a result, this new engineering curricula contributes to new engineering knowledge; ensuring students understand the impact of professional behaviour and their potential to contribute to societal welfare. These are lifelong skills and critical attributes for engineers engaged in new product development.

Chapter five: Collaboration with industry

5.1 Overview

Chapter One identified 'industry readiness' as a key graduate attribute for roles in new product development. In Chapter Two, the global survey of Product Design Engineering curricula identified industry-led projects as fundamental to the relevance of this new discipline.

Industry collaborations develop real-world product development methods and provide a validity and relevance to student outcomes. Students have the opportunity to develop professional attributes and benchmark themselves against industry standards in product design. The benefits include the establishment of strategic relationships for the PDE program, resulting in more relevant curricula, more focused studio projects, new research and development opportunities for industry partners, and enhanced employment pathways for graduates.

This chapter discusses industry engagement, in the final year capstone project, and examines barriers to successful collaboration with industry from both a learning and design outcome perspective. It draws from the following conference paper, presented in September 2008 at New Perspectives in Design Education, the 10th International Conference on Engineering and Product Design Education, organised by the Universitat Politecnica de Catalunya, in conjunction with the Design Education Special Interest Group (DESIG) of the Design Society and the Institution of Engineering Designers (IED).

> de Vere, I. (2008) Managing Industry Collaboration: Providing an Educational Model in a Client-Led Project, the *10th International Conference on Engineering and Product Design Education (E&PDE08)*, Universitat Politecnica de Catalunya, Barcelona, Spain.

The chapter concludes with Case Study 4, *An Industry-led Capstone Project* which describes the final year project in the Swinburne Product Design Engineering program, where individual students work collaboratively with industry and community partners to develop appropriate and well-resolved design solutions.

5.2 Introduction

Collaborative projects with industry partners are critical to the relevance and success of the Product Design Engineering discipline. Such projects permit student access to 'in-house' industry experience and provide critical analysis and feedback from a commercial, not just academic, perspective. Consequently, these collaborative projects contribute to the industry relevance of the curriculum and the readiness of PDE graduates for employment in new product development industries.

The industry partners offer technical and manufacturing knowledge, whereas the community partners offer understanding of the market and user needs and environs. Issues arise when student objectives and educational requirements conflict with the commercial constraints of the industry partner. The student's learning experience and creativity may be restrained by economic or manufacturing restrictions imposed by their project partner. The project intent must be carefully aligned with the expectations of all stakeholders, especially industry partners who provide technical expertise and resources, often with the expectation of free research and development.

This chapter examines the task of facilitating the students' educational needs and the development of the design, assisting the collaboration process and managing the expectations of all parties; industry, student and university. The educational merits of, and barriers to, effective industry engagement are evaluated in the context of real-world learning, and preparation for roles in new product development industries.

5.3 Industry engagement

The final year 'capstone' project allows students to fully express their integrated design and engineering skills. In these projects industry engagement contributes significantly to the learning experience. "Industry involvement in engineering education improves the relevance of education, better prepares students for employment, provides industry with a better qualified workforce, and creates synergy between industry and academia" (Lewis et al. 2006, p. 591).

59 percent of the surveyed PDE programs (refer Section 3.10.7) utilise industry-led projects where students benefit by collaborating on 'real' projects, enhanced by real-world industry feedback and critique, encouraged by the possibility of the project progressing beyond university submission to a manufactured outcome. The projects can also prove beneficial to the industry partner as students are not encumbered by company policies or hierarchies, or established practices. This can lead to new insights and creative possibilities, and subsequent design innovation.

Collaborative industry projects require synergy and commitment (from university, industry and student) for the year-long duration of the project. They can result in extra pressure on students; however this is offset by the opportunity for students to engage with potential employers, work on actual industry projects and measure their capabilities against 'best practice' industry criteria. In the example below (Figure 5.1) the final year PDE student worked closely with a government and industry funded research centre (the Cooperative Research Centre for Wood Innovation) to improve accuracies and efficiencies in the commercial wood forming industry.

Figure 5.1: Wood forming equipment using linear actuators to retain the shape during the drying process –a collaborative research and design project
(image source: final year Swinburne Product Design Engineering student)

5.4 Project Issues

5.4.1 Managing Expectations

Of ongoing concern are the issues of balancing industry partner expectations against educational needs. It is essential that students, their external partners and teaching staff achieve the correct balance between facilitating student learning and achieving a realistic and viable product outcome. The project should have commercial product potential, but must offer the full scope of academic, engineering and design challenges, as appropriate for a final year ‘capstone’ project.

Issues may arise when the objectives of the student and the educational requirements of the project clash with the commercial realities of the industry partner. Lecturers must ensure that industry partners are cognisant with project scale and understand their participatory role is more mentor than client. The learning experience may be limited by technical or manufacturing restrictions imposed by the industry partner, who may have internal processes and commercial self-interest, ahead of the most appropriate design solution.

Students may need to extend the parameters of their project to express their potential and achieve an appropriate learning and product outcome. It is important for the industry partner to acknowledge that this is fundamentally a university project, not a commercial research and development program, and set their expectations accordingly. Involvement with the project is not a no-cost alternative to employing the services of a professional (Siegel 1996). Whilst many of the student outcomes have excellent commercial potential, student designs will require significant development before the product is ‘market-ready’ and partners need to understand that educational priorities must take precedence over commercial interests.

5.4.2 Managing the collaboration

The issue central to effective industry collaboration is communication. Developing and maintaining collaboration with appropriate industry partners is essential to consistent project progress. “The success of a project can often be determined by the frequency of interaction between (industry) liaison engineers and students” (Dutson et al. 1997, p. 22).

Unfortunately, students often lack courage when initially approaching industry or maintaining continuous liaison, particularly if they perceive their career prospects are under scrutiny. It has often been observed that students will forge ahead with the product development process (without industry consultation) for fear that engagement may lead to design revisions and an increased workload. In such cases the direction of the project and the intent of the product may be lost, adversely affecting the final outcome, and negating the benefits of working collaboratively.

Teaching staff must monitor the student-industry relationship carefully to ensure that effective communication is ongoing, the industry partner's feedback is informative and that appropriate levels of technical and contextual support are forthcoming.

5.4.3 Maintaining a realistic and achievable outcome

Projects must be carefully mapped to ensure that the intent is achievable in the time frame and with the available resources. Students must balance the expectations of others against their own abilities, their workload in other areas of study and the academic requirements of the subject. Often project proposals require 'downsizing' to a more achievable level; e.g. a project starting as a vehicle interior targeting an aging population, may become an investigation of vehicular ingress/egress systems with the resultant design being a rotating-track seat mounting.

Figure 5.2: Design for aging demographics - a vehicle egress- ingress project with multiple partners – an aged care support agency, the Cooperative Research Centre for Advanced Automotive Technology and a leading manufacturer of automotive interiors (image source: final year Swinburne Product Design Engineering student)

5.4.4 Ensuring manageable student workloads

Whilst capstone projects are run over two subjects and two semesters, they often represent only a small proportion (e.g. 25 percent) of the student's academic requirements in their final year, yet consume their workload and quickly become the primary focus. As the last major project, students are determined to make it their crowning academic achievement, and view the final outcome as an essential element to initiate a professional career.

This can cause excessive stress levels, and be to the detriment of other areas of study. Teaching staff must carefully monitor workloads to ensure that the project intent is feasible within the scope and time constraints of the project, the level of external support and the student's ability. Lecturer input during planning and implementation is crucial to ensure the project is realistic, manageable and achievable despite the expectations of other subjects/lecturers and student organisational skills.

5.4.6 Student Feedback

As found by Welsh and Murray (2003), end of semester evaluations frequently do not reflect the student energy and enthusiasm experienced during semester. Feedback through on-line student satisfaction surveys which are conducted every semester often reflects student frustration with their project progress, workload pressure and timeline management issues. This is indicative of a student cohort that has been micro-managed throughout their studies, and who haven't yet developed the requisite organisational skills.

Students in this self-directed project often struggle with project planning and direction. As they are not used to controlling the agenda, they often expect lecturers to provide more direction and supervision than is appropriate in a self-directed project. They are not always comfortable with lecturers taking redefined roles as facilitators and mentors, rather than more formal teaching approaches. However, it is critical that students 'own' the project and take full responsibility for the project outcome if the desired gradate attributes are to be achieved. Students must work independently and develop professional methodologies and whilst negative student feedback is never welcome, lecturers understand that, as noted by Palmer (1998), student dissatisfaction can be indicative that significant education has occurred.

5.5 Conclusion

Working closely with industry partners develops real world methods and provides a validity and relevance to student projects. Students have the opportunity to benchmark themselves against industry standards in product design and development. The resultant designs incorporate emerging technology, new materials and sustainable manufacturing into innovative solutions that address societal need.

Industry involvement in student projects can lead to improved strategic relationships and more relevant curricula, and provides new employment pathways for the student and their peers. The students benefit from the relationship by being better prepared for the *practice of engineering*, through the opportunity to balance theory with real world practice (Dutson et al. 1997). This is essential for those engineers seeking employment in new product development.

Industry-led experiential learning design projects allow analytical knowledge to be applied in a commercially realistic application with full industry analysis and thorough validation resulting highly desirable graduate attributes and employability. As found by Dutson et al (1997), the success of capstone projects such as this can be measured through the interest expressed by industry in graduates who have experienced such a rigorous process. The professional attributes developed through such projects (including project planning/management, applied and market research, engineering analysis and product validation), facilitate graduate employment and more rapid career progression into roles of responsibility.

However, industry expectations must be balanced with the students' educational needs to ensure realistic and achievable outcomes and manageable workloads within the timeframe. This requires the early establishment of communication and collaboration management tools ensure a positive learning outcome.

The Swinburne 'Professional Project' articulated in the following Case Study 4 is typical of industry-led capstone projects within the Product Design Engineering discipline. This capstone project allows the 'client' to lead the product agenda within a carefully controlled learning environment, whilst imbuing the student with responsibility, independence and management skills. Resultantly, graduates are better prepared to contribute to new product development. The collaboration with professional designers and engineers, whilst mimicking actual product development processes, has added benefits in developing and demonstrating students' problem framing and solving abilities, key graduate attributes discussed in Chapter 6.

Case study 4: An industry-led capstone project

Introduction

This case study examines the self initiated and directed final year ‘professional project’ which is the culmination of study in Product Design Engineering at Swinburne. In this industry-led project, students undertake initial research to identify a worthy social need, determine a project direction and design intent, and then collaborate closely with external industry and community partners to realise a successful and appropriate product outcome.

Project overview

Student projects must address social, humanitarian, community environmental or sustainable needs. It is expected that design outcomes are products without precedent, which represent sustainable practice, innovative user-centred design and creative new product development.

Final design outcomes are expected to be creative in design and innovative in the application of engineering theory, whilst meeting societal and market needs and manufacturing objectives. The project also requires that design outcomes are critically analysed including design for assembly/disassembly, life cycle analysis, finite element analysis and failure mode effects analysis. The outcomes are documented in a thorough technical report containing the full journey of applied research, design rigour and engineering analysis and validation.

Project Proposal

These final year capstone projects provide students with the opportunity to utilise all of their skills and knowledge in the research and design of a product in collaboration with external partners. Individual projects are self-initiated and transpire in one of the following ways:

(a) The student conceives the project, and then seeks suitable industry and technical partners for support with technology, project definition, and user needs.

(b) Lecturers introduce students to appropriate companies who suggest a research project, usually one that applies their emerging technology to a specific need.

(c) Students engage with disability support organisations, healthcare providers, humanitarian groups and NGO aid agencies (such as World Vision, Engineers without Borders etc) seeking to contribute to ongoing humanitarian projects.

(d) Students approach industry or university research organisations seeking new or emerging technologies that require product applications.

(e) Students returning from a year of industry-based learning, bring a project of mutual interest from their internship employer, thus ensuring a continuing relationship which may lead to graduate employment.

Project approval

Project proposals are carefully vetted for educational suitability, research potential and opportunity for product innovation prior to approval. Projects are presented to a review panel consisting of design and engineering lecturers early in the first semester for approval and project guidance. This process ensures that the proposal meets the project requirements, is supported by appropriate and informed industry partners and is of sufficient academic, engineering and design rigour to sustain the student for two semesters of activity. Students must have research findings that identify the social need, define and justify the project, and distinguish the proposal from existing products or solutions.

Industry partners

Students must develop effective relationships with their external partners. These partnerships facilitate technology information exchange, access to market data and user demographics, manufacturing knowledge and technical support, and commercialisation opportunities. In the case of humanitarian or healthcare projects, partners provide the critical link to understanding the end user and their environs.

Students may have several partners during the project, each making a different contribution according to project progression. Initially the student requires market and technology information to define the product, later it is imperative that partners provide critical analysis of designs proposals, assist technology implementation and ideally, commit to product development after project completion. For example, a student may work closely with an NGO for initial scope and discovery, and then engage with a manufacturer or technology provider for design resolution, or product realisation.

Maintaining effective industry collaboration

As developing and maintaining collaboration with appropriate industry partners is essential to consistent project progress, teaching staff must monitor the student-industry relationship carefully. Students are required to document the collaboration process by maintaining a contact log of their consultations with industry support partners, in order to provide evidence of successful engagement. In addition, industry partners are asked to complete project evaluation sheets (examining both process and outcomes) at the end of each semester. This feedback contributes to the students' final assessment, and has become a valuable reflective process.

Teaching objectives and delivery

The final year capstone project requires the student to take responsibility for their individual project, whereas the lecturers revert to less formal mentoring and facilitator roles, similar to the role of an R&D manager. Whilst some formal instruction occurs through lectures, mostly to do with process and expectations, it is the students who 'own the project, establish and manage timelines and determine the research, design and engineering tasks necessary for successful project completion and a viable product outcome. This self-directed learning, facilitated by lecturer guidance and support, aims to establish an independent student methodology, and to measure student competency in a close approximation to industry practice.

Project outcomes

The project culminates in a 16,000-word technical report, a professional document of design, engineering and academic rigour. A prototype and a design folio containing conceptual, developmental and production drawings support the project progression.

At the end of the each semester, design outcomes are presented to a review panel comprising design and engineering academics and representatives from industry. Student presentations outline the product need, the research and development process and must validate the final design against research findings, engineering analysis and other social and environmental criteria. Industry partners and program collaborators will offer specific awards for student projects that satisfy specific requirements, e.g. most sustainable design, best resolved for manufacture. The award recipients are nominated by the project assessment panel immediately after the final presentations.

Research process

The research component of the project which occupies a substantial amount of the first semester, must include:

- project planning (Gantt charts)
- literature review
- IP / existing patents, relevant standards and design rules
- ergonomics, anthropometrics and human factors
- market analysis,
- user demographics and needs
- competitor product benchmarking
- SWOT and PESTE analysis, Porter 5 Forces, House of Quality analysis

This extensive process is conducted throughout Semester One, prior to the design conceptualisation stage. Student's research findings form the basis of their written thesis, and inform the product design specification, which describes project intent and product functionality.

An interim 8000-word technical report is submitted at the end of semester one, which will then be revised and incorporated into the final end-of-year report.

Design process

Projects progress through research, analysis, concepts to synthesis in a reflective and well planned process. The design and development utilises the development methodology described by Ulrich and Eppinger in their definitive text, Product Design and Development (2008) with regard to project planning, identification of customer needs, product specification, concept selection and design for manufacture.

Following the research, an informed ideation stage occurs with conceptual designs addressing the product design specification generated, presented and evaluated prior to the end of the first semester. These concepts are then subjected to rigorous scrutiny and analysis (including concept screening and scoring) against defined researched customer needs and proposed product metrics, before a concept direction is chosen for development.

The second semester involves design development, product embodiment, technical resolution, prototyping, engineering analysis, testing and validation processes, manufacturing documentation and costing, and the finalisation of the technical report which documents the entire project.

Engineering analysis

As part of the product resolution process, designs must be critically analysed against established criteria including:

- design for assembly/ disassembly (DfA) and design for manufacture (DfM)
- design for the environment (DfE) - including life cycle analysis (LCA)
- finite element analysis (FEA) for strength and deformation
- failure mode effects analysis (FMEA)

These product development and analyses form the second half of the technical report. Manufacturing costs and subsequent product prices must be calculated (including tooling amortisation), and designs validated against identified market needs and the product design specification (resulting from the research phase).

Product outcomes

Engineering rigour must underpin all student designs. As the PDE course is multidisciplinary, aptitude in both design and engineering must be reflected in the final project outcome. The application of engineering theory must be documented through research, calculations, formulae and analysis whilst designs must be user-centred, sustainable and use appropriate technology, materials and manufacturing processes and be resolved to final prototype stage, ready for field testing. Project outcomes cannot be conceptual designs; they must be fully resolved products.

Students are expected to make a convincing case for product implementation, due to research, design and engineering rigour manifested into an appropriate, well resolved product design. The supporting documentation of technical report and design folio should justify the need for the proposed product and validate the design outcome.

Effective Teaching Methods- digital learning

With thirty or more students engaged in the development of different products (addressing differing needs), it can be difficult with limited consultation time to quickly evaluate a student's progress and for the students to effectively communicate the details of their design. However, in recent years this project has been included in Swinburne’s Digital Learning Initiative, where selected students were issued with a laptop, loaded with design, engineering, communication and project management software. As a result of this initiative, the final year PDE students can utilise class time more productively to further their designs, communicate their project progress effectively and seek peer review and assistance. 3D-CAD, internet research, data sharing and peer-to-peer information exchange are now common within the studio environment, greatly assisting the teaching and teaching process. Students are benefiting from improved communication pathways and research access and peer-assisted learning, and lecturers are able to monitor project progression more closely.

Intellectual Property

As University policy allows students’ full ownership of their design outcomes within their projects, students are also free to negotiate with industry partners to realise the product commercially. Teaching staff are often drawn into this process, helping both student and company define their respective contribution to the final outcome.

Early in the project, a patent attorney provides lectures on intellectual property rights, to facilitate royalty agreements. Lecturing staff are often required to sign non-disclosure agreements with emerging technology partners, and specific details of a student's design are sometimes precluded from display at the graduate exhibition because of the sensitive nature of either technology or application. Whilst these issues can be problematic and intimidating for students, they provide a realistic commercial framework and may indicate that an industry partner recognises the potential of the proposal, thus validating the design outcome.

Well-articulated agreements can lead to successful outcomes for the student, including employment post-project and future royalties. For example a foetal heart monitor (shown below in Figure Cs4.1) has progressed and a design consultancy been engaged by the student's industry partner to finalise development and oversee production. The graduate has been placed into the consultancy to project manage the development of her design.

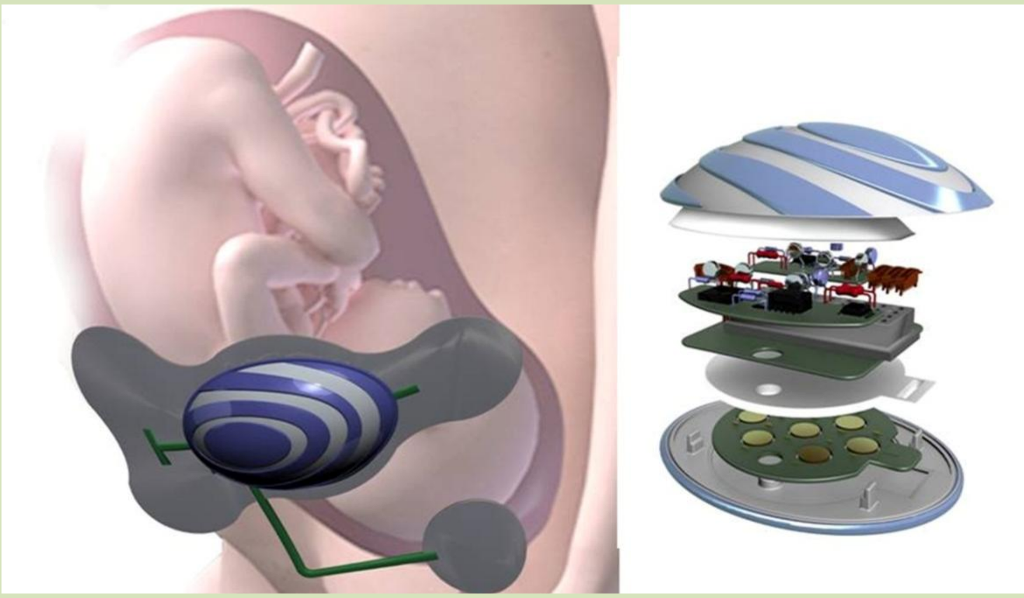


Figure Cs4.1: A wearable foetal heart monitor for constant monitoring of the foetus in the weeks leading up to birth, resulting in improved pre-natal care and early detection of health concerns. (image source: final year Product Design Engineering student)

Project Achievements

Designs into production

Whilst commercialisation is a desirable outcome, it is not intended that this project result in the manufacture of student designs. Students are often reluctant to engage any further in the development process having completed the academic requirements of the project. Students will utilise their project research and design documentation to prove their credentials for employment, and after course completion will see the project as having achieved its purpose. In other cases, partner companies lack the funding or managerial commitment to invest in prototyping, field-testing, pre-production development and manufacture.

Despite this, many projects have proceeded into further development. It is anticipated that more than 30% of current or recent projects have industry partners keen to continue development to production. These products include:

- revolutionary quarter-saw timber milling equipment (Figure 3.8),
- the aforementioned foetal heart monitor,
- an innovative vehicle ingress/egress system (Figure 5.1),
- a roadside drug testing system (Figure Cs3.9),
- a fitness device to tackle childhood obesity (developed in conjunction with a leading sportswear manufacturer),
- a ventilation energy recovery system for large HVAC installations,
- a prosthetic arm for Cambodian amputees,
- a water dispensing system to eliminate disposable bottles (Figure Cs1.9),
- a small scale MRI for medical practitioners,
- a water purification infrastructure for remote villages, and
- a sleep apnoea respiratory mask.

Whilst it is rewarding to see student designs become commercially considered, it is important for students and industry to understand that the learning outcome is more important in design education, than the project outcome.

Figure Cs4.2: A small scale MRI machine for quick analysis by medical practitioners, eliminating the need for referral to imaging centres.(image source: final year Product Design Engineering project)

Figure Cs4.3: water purification system for small village, already in production (image source: final year Product Design Engineering capstone project)

Figure Cs4.4: A sleep apnoea respiratory face mask has generated significant commercial interest. (image source: final year Product Design Engineering capstone project)

Learning outcomes

The Swinburne PDE 'professional project' succeeds as a showcase of student skills and abilities and provides industry relevant and commercially realistic outcomes. Students are able to demonstrate a wide range of design, engineering, liaison and project management skills; leading to increased employment opportunities. The project requires students to demonstrate initiative, develop entrepreneurial skills, and collaborate with industry partners and research organisations to develop an innovative product.

Students are provided an opportunity to integrate knowledge and skills acquired during the course, in a design solution that includes mechanical engineering theory in a product context. More importantly, the engagement with industry and communities develops professional methodologies and results in rigorous design processes and validated design outcomes, measured against industry expectations. Students learn to conduct thorough research, which drives design development, and to use their engineering analytical skills to improve and validate their design outcomes.

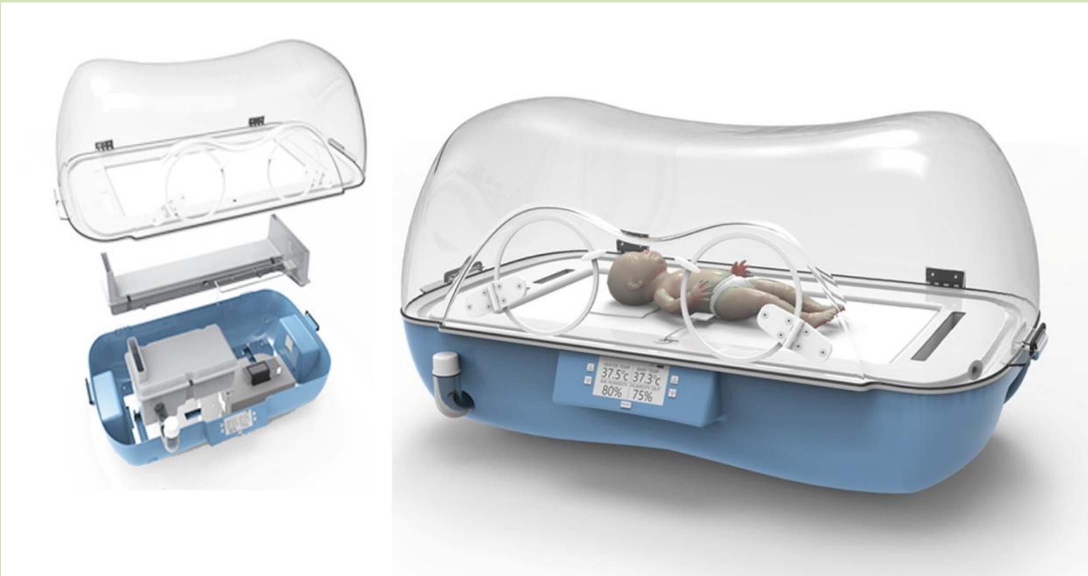


Figure Cs4.5: a infant incubator for developing nations utilises low-technology manufacture (image source: student generated design- final year Product Design Engineering)

In the example above (Figure Cs4.4), this student design for a low-cost infant incubator, aims to address the UN's Millennium Goal No. 4 (to reduce the under-five mortality rate by two-thirds by 2015) by providing a low technology solution that can be locally manufactured using simple manufacturing processes (e.g. vacuum-forming), and provides evidence of a high level of societal understanding, consideration for user needs, and resolution for manufacture.

Conclusion

Industry-led projects offer substantial opportunities for real-world learning, underpinned by manufacturing and budgetary constraints and commercial realities. Students gain valuable insight into the processes of design consultation and client engagement, design for manufacturing, design for market and product production. As found by Dutson et al. (1997), "having students feel responsible and accountable to an industrial "customer" seems to be an important factor in their learning the practice of engineering" (p. 22).

The opportunity to address industry and community mandated design brief through collaborative processes enable greater empathy and understanding and provide opportunities for the student to demonstrate prowess in creative design and innovative engineering. The project also allows students to develop strategic relationships with industry, and can lead directly to graduate employment. From the 2012 graduating year, it is anticipated that up to 20 percent of students will secure employment with their industry partner.

The capstone project at Swinburne is an example of a sustained student-industry collaboration which has resulted in new product innovation and enhanced employment opportunities for graduates. As such, it is a fitting conclusion to the four year undergraduate degree course.

Chapter six: Evaluating design and problem-solving ability

6.1 Overview

In earlier chapters, the challenges facing engineering in the 21st century' were discussed, and the ability to deal with ill-defined problems (Cross 2006), was highlighted as a key graduate attribute.

This chapter discusses a comparative evaluation of problem-solving aptitude amongst final year undergraduate engineering students from the Mechanical Engineering and Product Design Engineering courses at Swinburne.

The chapter content is drawn from a peer-reviewed conference paper that was presented in Norway in September 2010, at the 12th International Conference on Engineering and Product Design Education, organised by NTNU in conjunction with the Design Education Special Interest Group (DESIG) of the Design Society and the Institution of Engineering Designers (IED).

> de Vere, I., Kuys, B., Melles, G. (2010) A Comparative Evaluation of Aptitude in Problem Solving in Engineering Education. *12th International Conference on Engineering and Product Design Education, (E&PDE),* Norwegian University Of Science And Technology, Trondheim, Norway.

This paper was written with one of my supervisors, Dr Gavin Melles, and teaching colleague Dr Blair Kuys, who convened the design studio in which the comparative evaluation occurred. The comparative evaluation was conducted to achieve two objectives, firstly to evaluate design and problem-solving skills and secondly to measure the effectiveness of the Product Design Engineering (PDE) curricula as a training medium for roles in new product development.

The results of the comparison of mechanical and Product Design Engineering students highlight the benefits of a design-based approach to engineering education. Also evident is the significance of the design project in providing experience in translating engineering theory to practice. The results provide valuable insight into the benefits of the multidisciplinary PDE program with regards to design creativity and engineering problem-solving, in a product design context.

6.2 Background

"It is implicit that creativity is integral to design innovation, and that design and the fostering of creativity should be the cornerstone of engineering pedagogy"
(de Vere 2009, p. 342).

Earlier in this research, the literature revealed that engineering education has been criticised for focusing solely on the science of engineering, to the detriment of the development of non-technical (soft) skills, such as creativity, design acumen and problem-framing aptitude (Pappas 2002; Santamarina 2002; Dym, Agogino et al. 2005). Students must be challenged to move beyond the technical aspects of the problem (Stouffer, Russell et al. 2004) and develop creativity through new non-linear, unstructured and flexible approaches to problem-solving and idea generation. (Pappas 2002).

The creative process involves having unusual ideas, tolerating the unconventional and seeking the unexpected (Cropley and Cropley 2000). This makes open-ended problem-solving particularly challenging for engineering students who are more comfortable when working within defined parameters and pre-determined results.

Traditional engineering assignments, tend to be left-brained, with constrained parameters and predefined outcomes (Fry 2006). Such curricula does not develop creative thinking (Pappas 2002), and may result in graduate engineers who are inclined to fixate on prior solutions, limiting their potential to contribute to product innovation. If graduates are to be creative design engineers, curricula must develop design acumen, and develop aptitude in open-ended problem solving.

6.3 Introduction

Engineering education has been criticised for not adequately developing creativity, design aptitude and problem framing, despite these skills being identified as key graduate attributes, especially for engineers engaged in new product development. Grasso and Martinelli (2007) question "whether we are adequately preparing our future engineers and designers to practice in an era that requires integrated and holistic thinking, or are needlessly limiting their solution spaces to those that contain only technological answers?" (p. B8)

Cropley and Cropley (2000) identified that many Mechanical Engineers are considered by new product development employers to be ill-prepared for real world problem-solving and to have limited experience in applying their engineering knowledge to product outcomes. Formal instruction in design is uncommon in mechanical engineering curricula, and where existing, is usually in a technical context, e.g. machine or mechanical systems design. This style of design instruction follows a linear, problem-focussed process that limits opportunity for creative exploration. By contrast, the multidisciplinary PDE pedagogy integrates design project-based learning and open-ended problem solving throughout the curricula. The effectiveness of this approach should be revealed by the comparative evaluation.

6.4 Rationale

HES5350 Product Design is an elective subject offered to all student disciplines within the engineering faculty at Swinburne University of Technology. The content and delivery of this subject, aims to impart:

- an understanding of product design processes,
- an appreciation of design principles in engineering, and
- the ability to creatively respond to design problems with product outcomes.

As both Product Design Engineering (PDE) and Mechanical Engineering (ME) students attempt the subject in the final semester of their fourth (and final) year, the unit provides a unique opportunity to compare student ability in product design and problem-solving across different engineering disciplines. As the subject included specific design projects requiring creative and user-centred solutions, it facilitated a comparative evaluation that measured the problem-solving aptitude of the different engineering disciplines.

As Product Design Engineering derives 60 percent of its content from the mechanical engineering curriculum, it was expected that a comparative evaluation of PDE and ME student abilities would highlight the contribution that the inclusion of design curricula has made to engineering capabilities, especially in regard to product design. The evaluation did not intend to expose inadequacies in the skills and attributes of mechanical engineering students. Rather, it was hoped that the evaluation would provide evidence of the benefits of integrating design curricula into engineering learning in the context of preparing engineers for roles in new product development.

6.5 The Comparative Evaluation

The participants in this study were Swinburne final year students from the Mechanical Engineering and Product Design Engineering programs. Students' problem-solving methods were observed, the design outcomes were evaluated and the participants were surveyed. The exercises challenged the student's problem framing and solving abilities and required the application of engineering science and design acumen to achieve a creative and human-centred solution.

The unit challenged students to complete two three-week design projects, addressing:

- an open-ended or 'wicked' problem, and
- designing to a highly constrained brief.

Students were not assessed on specific design skills (such as drawing and presentation skills) to ensure that the ME students were not disadvantaged. Both projects required creative problem-solving ability, the application of engineering knowledge, and consideration of the needs of the intended user and their environment, as is normal in product design. Projects were distributed randomly and where possible, students were engaged on different problems to their closest peers.

6.5.1 Issues with problem scoping

Atman *et al* (1999) found in a comparative study of freshman and senior engineering design processes, that novice students did not produce quality designs, even though they spent a large proportion of their time defining the problem. By contrast senior students with more developed 'problem scoping' aptitude, analysed and framed the problem more efficiently, enabling them to progress to better design outcomes. It was also recognised that the more experienced students had enough confidence to make assumptions which aided the analysis process. The progress of novices often stalls at the problem definition stage resulting in delays or poorly considered design solutions.

The main difficulty in teaching the diverse student cohort in this study was the lack of parity in design and problem-solving abilities. It was quickly apparent that whilst the PDE students benefited from a design-focussed education had enabled their progression from novice to expert, the fourth year ME students (with relatively little design training) were design 'novices' unfamiliar with the demands of unconstrained design processes, despite being in their final semester of study.

Whilst the PDEs had well developed design acumen, after years of design project based learning, and were comfortable with the uncertainty of the design challenges, the ME students lacked confidence and the sketching abilities necessary to encourage creative exploration. Consequently, the ME students required significant tutoring, especially in ideation techniques and perspective sketching, and a disproportionate amount of lecturer assistance during the project.

Atman's findings were reinforced by this research. The ME students, troubled by problem definition, failed to address the real needs of the project, focussing on the more tangible technical aspects, whilst the PDE students typically identified crucial user needs and environmental or contextual requirements, resulting in thorough framing of the problem and ultimately, successful designs.

There was also evidence that the PDE students used 'generative' reasoning, as identified by Lloyd and Scott (1994) and a solution- focussed approach, whereas the ME students tended to engage in deductive reasoning.

6.5.2 Measures of comparison

The comparative evaluation projects occurred within a design teaching studio environment, although project progression was not limited to in-class time. The comparisons between the problem-solving aptitude of the PDE and ME students were evaluated through a variety of measures including:

- direct observation and recording of problem-solving and design processes,
- discussions with students during the project to gain insight into their processes and difficulties,
- evaluation of the final design solution, and
- an anonymous reflective post-project survey.

6.5.3 The student survey

The reflective survey addressed sketching /conceptualisation, problem-solving and project analysis. Students evaluated their level of comfort with either open ended or constrained problems, examined the impact of their sketching abilities and provided an overall evaluation of the project.

The survey sought to capture the students' reflection on their:

- ability to communicate ideas through drawing,
- familiarity with user-centred design,
- comfort with short lead-times,
- skills in critical thinking and analysis,
- application of engineering skills to real-world problems, and
- ability to develop appropriate and innovative product solutions.

6.6 The Design Challenges

The two projects enabled observation and evaluation of the difference in abilities and approaches of final year engineering students when confronted with a real world problem requiring a creative product solution.

The conceptual open-ended Project 'A' required a user-centred focus and a creative and divergent approach, whereas the more technical constrained Project 'B', required understanding of materials and manufacturing processes, and the principles of structural engineering.

The study aimed to discover which discipline of engineering students (PDE or ME):

- is more adept in either open-ended design or constrained problem-solving,
- demonstrates creative design ability in a product design context,
- best applies technical knowledge to product resolution, and
- demonstrates consideration of user needs and environment considerations.

6.6.1 Hypotheses

Some assumptions or hypotheses regarding the students' potential were made prior to the commencement of the projects.

Firstly, it was assumed that the Product Design Engineers would perform better at the open-ended project due to the in-curricula fostering of their creativity, their familiarity with ill-defined problems, and their extensive design experience.

Secondly, it was expected that the PDE students would have an advantage over the ME students, as their sketching abilities would lead to a more reflective design process and further enable the articulation of product design solutions. Consequently, the MEs were taught perspective sketching techniques to help them to explore, experiment and express their ideation.

Thirdly, it was deemed important to include a project that was tightly constrained. As the engineering profession is often engaged in projects with defined parameters and restrictive specification, it was important to evaluate the students' effectiveness at problem-solving in a more familiar situation. The constrained project required application of manufacturing and material and structural engineering knowledge, and did not necessarily favour either discipline, although it provided an opportunity for the ME students to excel.

6.6.2 The open-ended or 'wicked' problem

Project 'A' required students to design a product for use in developing nations or remote areas where communities may be located at some distance from sources of clean drinking water. In such situations, people are required to transport water long distances without vehicular support, often many times daily. Students were challenged to design a solution that enabled the movement of 80 litres of water either up and down steep rocky terrain, or across a flooded plane preferably by a single person. Typically in these situations it is women and children who do the water carting, so it was critical that their relative size and strength were considered.

A creative user-centred approach, systematic problem definition and the appropriate application of engineering principles were necessary for a successful outcome. It was implicit that students would consider user-safety, in particular directional control and braking, as well as handling, refilling and pouring and other critical user needs. These project criteria were not identified during the project briefing, to allow lecturers the opportunity to observe students' discovery processes during the problem framing stage.

6.6.3 The constrained problem

Project 'B' was a highly constrained problem where students were tasked with the design of a lightweight cafe stool to be fabricated from a single piece of mild steel sheet. The furniture was required to be safe and stable, support the load of a 100kg person, suitable for outdoor use in the public domain, and address cafe stacking and storage demands. Students were challenged to utilise sheet steel fabrication processes (such as pressing, rolling, folding, stamping) and balance structural needs with situational needs such as aesthetics, weight and comfort.

A further requisite allowed the steel sheet to be manipulated in multiple processes, but not cut into pieces and reassembled. This constrained and more technical project required application of knowledge of materials, manufacturing processes and structural engineering principles. Although project parameters were tightly defined, limiting the breadth of conceptual exploration, student designs were expected to be innovative and original (not adaptive), appropriate for cafe customers and the hospitality industry.

6.6.4 Assessment criteria

The engineering students' approach to problem framing / solving and their design process was observed closely by studio lecturers during the projects. In addition, both projects were assessed against assessment criteria of:

- creativity and innovation,
- originality of solution,
- user-centred design,
- consideration of user needs, culture and environs, and
- technical and manufacturing resolution

6.7 Analysis of Process and Outcomes

6.7.1 Studio observations

"Sketching enables the abstract development of a solution to an 'ill-defined problem' through the visualisation of mental imagery" (de Vere, Melles et al. 2010, p. 38).

It was observed that the ME students had difficulties with sketching, particularly in perspective. This limited the depth and fluency of their ideation, and also impacted on their critical reflective processes and subsequent design progression. It was also quickly apparent that the ME students had under-developed creative processes and were uncomfortable with ill-defined problems.

By contrast, the drawing fluency of the PDE students enabled a level of confidence that facilitated creative exploration. The PDE students typically utilised a divergent approach, whereas the MEs were too quickly convergent. The Product Design Engineers, fluent in design processes and the associated design skills were pro-active in problem framing and solution conjecture. This was not unexpected, as “expert designers are solution-focussed, no problem focussed” (Cross 2004, p. 439).

6.7.2 Week One

In the first design studio session, students should have been engaged in problem framing, rather than conceptualisation. The ME students, who were more problem focussed than solution focussed, were already developing their own variations of the ‘Hippo Roller’, an existing rope-drawn product, rather than pursuing unique and innovative solutions.

6.7.3 Week Two

In the second design studio, all students were engaged in conceptualisation, with the MEs struggling with sketching and ideation, exacerbated by the short time line.

In the open-ended project:

- prior solution fixation was evident, with many variations of the existing product solution (Hippo Roller),
- there was an overall lack of consideration for user needs or environs (e.g. traversing water or negotiating steep and rocky terrain), and
- the ME students were frequently uncertain how to proceed.

In the constrained project:

- students lacked understanding of metal forming processes/potential 3D forms, however some basic engineering principles, such as structural triangulation were emerging, and
- at this stage furniture forms involved simple folding fabrication. There was little evidence of material deformation to create complex curvature for structural strength.

6.7.4 Week three

By the end of the third week, all students had achieved a result, although not always an appropriate design. Results for the constrained project were much more successful with mostly unprecedented designs, whereas the open-ended project had a higher level of inconsistency and less innovative or unique solutions.

Overall results were better than expected, possibly due to frequent tutoring during the project. Lecturers noted a significant improvement in confidence and design ability as the project progressed, indicating that significant learning was occurring.

6.8 Analysis of outcomes

The final design outcomes were evaluated by lecturers against the following criteria:

- creativity and innovation,
- originality of design solution,
- evidence of problem framing and creative problem-solving processes,
- demonstrated understanding of, and response to, user needs and environs,
- technical resolution of final design – manufacturability, uses of materials etc,
- ability to broadly conceptualise without fixation on prior solutions, and
- innovative application of engineering knowledge in realistic outcome.

Lecturers did not directly assess skills, such as sketching, where great disparity existed between students ability. However lack of skills impacted on the success of the design progression and the subsequent final design outcome.

As these were final year engineering students, it was expected that all students, regardless of discipline, would possess sufficient design skills and engineering knowledge, to be capable of a systematic and sympathetic design process and achieve a well resolved design solution. This was not always the case. The study found significant difference in design skills, problem framing and solving ability and approach to product design tasks, between the Product Design Engineering students and the Mechanical Engineers. The benefits of developing a creative design focus within an engineering curriculum were clearly evident.

6.8.1: Analysis of open-ended project

The following chart (Figure 6.1) summarises the key criteria comparisons between the two student groups for the open-ended problem.

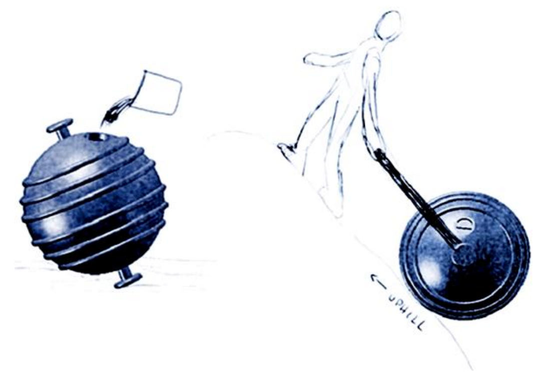
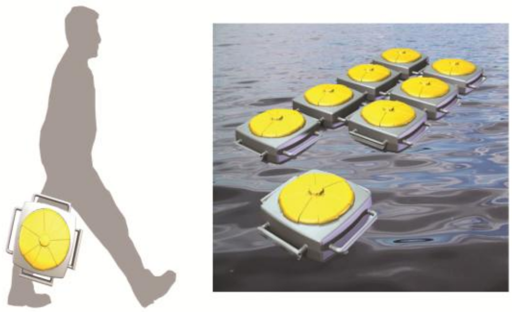
Mechanical Engineering students	Product Design Engineering students
	
All projects poorly resolved. 50 percent of outcomes not to an acceptable standard	Well resolved/flexible solutions, with multifunctional and modular designs for ease of handling
User safety not evident. Braking and steering systems not considered or resolved	All of the PDE students had resolved braking systems for safe ascent/descent
Lack of innovation. Universal fixation on variations of existing product	Some fixation on roller type solutions, but mostly innovative and original solutions
Flooded terrain scenario not addressed	50% of students addressed requirements of both steep and flooded terrain
All of the designs lacked technical detail and functional resolution	High level of technical and manufacturing resolution and attention to detail design
No user or ergonomic consideration e.g. filling, pouring or ease of handling	Highly refined functionality for user needs

Figure 6.1: Open-ended project – outcomes and analysis
(Image source: student designs - final year engineering project)

The Mechanical Engineering students did not succeed at the open-ended problem with most project outcomes poorly resolved. There was little consideration of user needs, in particular the safety aspects of braking and steering an 80kg mass over steep terrain, nor were filling or pouring systems resolved. In addition, the MEs' outcomes lacked technical detail and functional resolution when compared to the Product Design Engineers, who had framed the problem carefully, considering all scenario and user needs, and resolved their designs thoroughly.

Open-ended project outcome examples – Mechanical Engineering students

The following three images (Figures 6.2, 6.3 and 6.4) portray typical Mechanical Engineering student outputs for the open-ended (water transporter) problem.

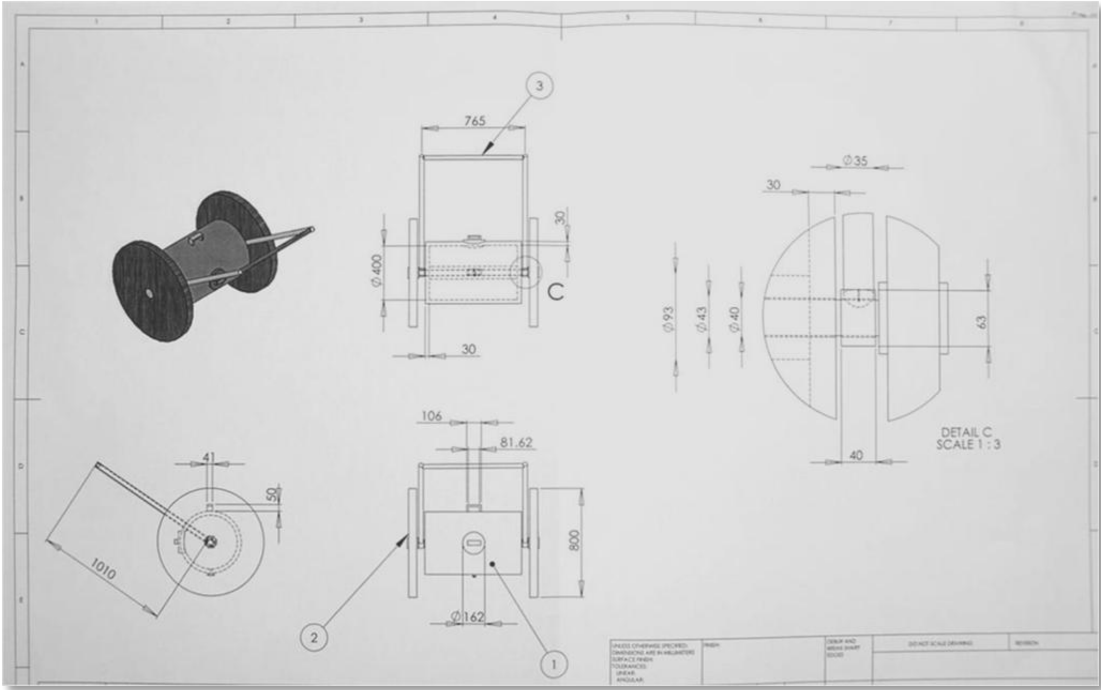


Figure 6.2: Mechanical Engineering student outcome 1.
An unrefined and poorly presented solution lacking consideration of user and context.
(Image source: ME student design - final year open-ended project)

Figure 6.3: Mechanical Engineering student outcome 2.
A poorly considered solution lacking braking, difficult to steer, poor ergonomics, no resolution of filling or pouring. (Image source: ME student design - final year open-ended project)

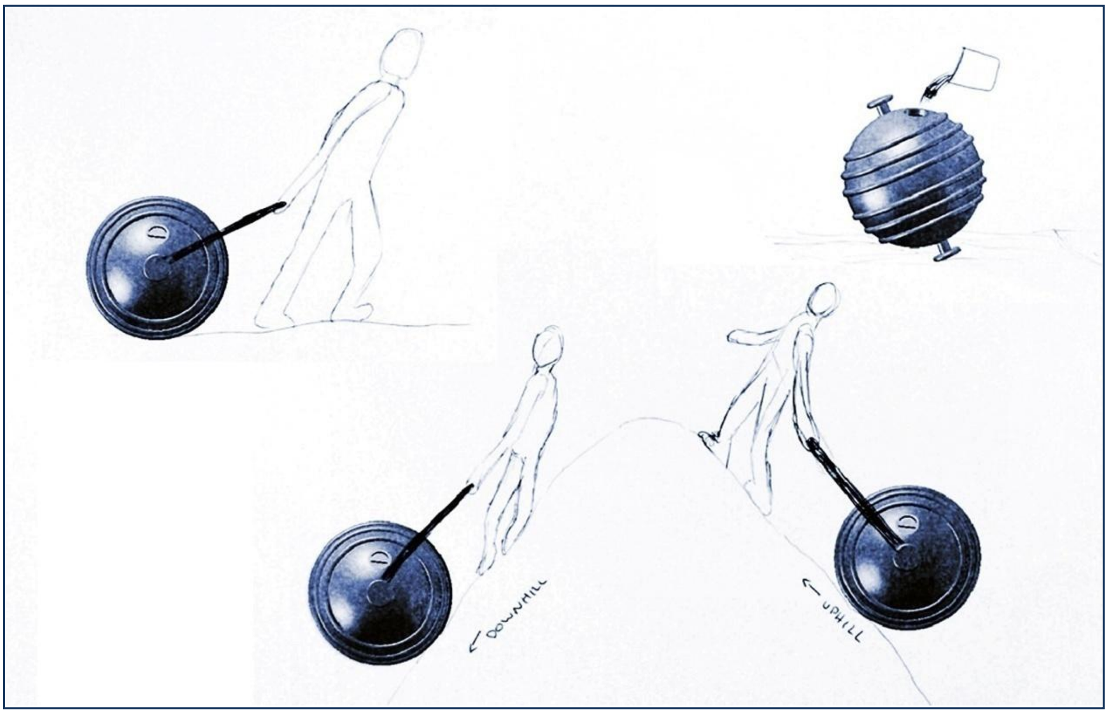


Figure 6.4: Mechanical Engineering student outcome 3.
Some user consideration (filling but not pouring), but no braking or steering capability.
(Image source: ME student design - final year open-ended project)

Many solutions were rudimentary in execution, lacked detail design resolution and understanding and empathy for the end user. The mechanical engineering students were hampered by poor creative problem-framing and design processes, lacked the necessary user-centred approach, and were not successful when applying their engineering abilities to develop an appropriate product solution.

Open-ended project outcome examples – Product Design Engineering students

The following images (Figures 6.5, 6.6, and 6.7) portray typical Product Design Engineering student responses to the open-ended (water transporter) problem.

Figure 6.5: Product Design Engineering student outcome no.1
- an innovative solution that utilises readily available found objects
(Image source: PDE student design - final year open-ended project)

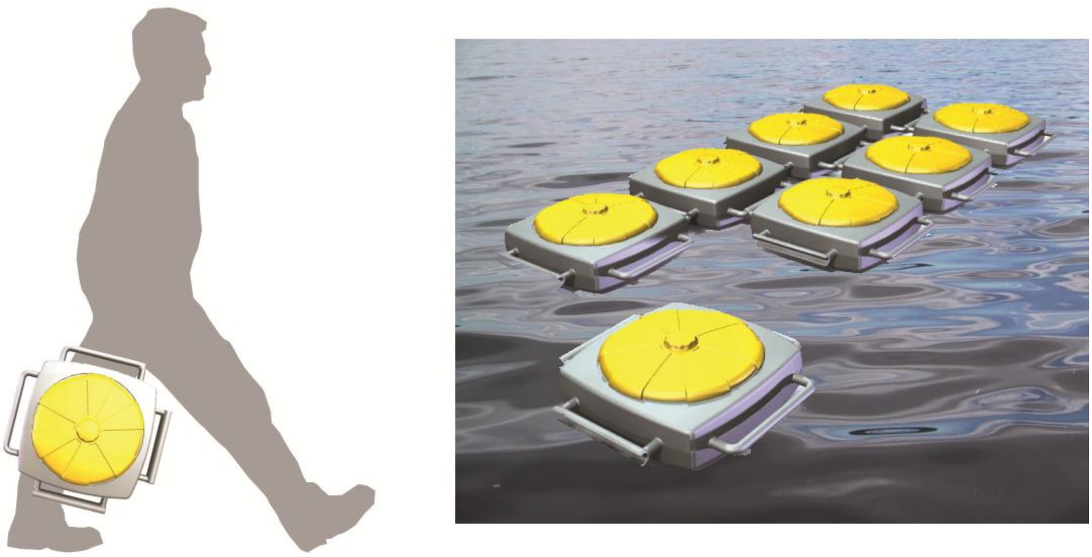


Figure 6.6: Product Design Engineering student outcome no.2
- an innovative modular solution that is easily carried and joins to form a raft for flooded terrain
(Image source: PDE student design - final year open-ended project

Figure 6.7: Product Design Engineering student outcome no.3.
The most innovative solution. A modular design that users interlocking segments to provide both roller and raft functionality. Fully detailed and resolved for manufacture, with user and contextual requirements considered. (Image source: PDE student design - final year open-ended project)

It is apparent from the examples shown above, that the Product Design Engineering students were more than comfortable with the open-ended design process. They moved quickly to frame the problem, and then engaged in a explorative and divergent conceptual design process, that involved a high level of consideration for both the end user and their operating environment. At least half of the PDE students presented multi-functional designs that could be used both in water and on land, and all of the PDE students incorporated braking systems for safe decent of steep terrain.

6.8.2: Analysis of constrained project

Figure 6.8 (below) summarises the key criteria comparisons between the two student groups for the constrained problem.

In this project, where all students were moderately successful with relatively original designs, the MEs utilised mostly simple and aesthetically unrefined 3D forms fabricated with sheet metal folding processes. Comfort, stacking and user safety (stability and metal edge finishing) were not fully addressed in the final design outcomes. By contrast the PDE students used more complex manufacturing processes to create visually striking, more comfortable and stronger structures.

An unexpected result was that the MEs, who were stifled by a lack of creativity, problem framing and design acumen in the open-ended project, were hindered in this more technical project by a lack of understanding of sheet metal manufacturing processes and the potential for complex form creation.

Mechanical Engineering students	Product Design Engineering students
	
Simple 3D forms. Only sheet metal folding processes were used	Complex 3D forms were created (including double curvature) for strength, visual appeal and comfort.
Solutions were mostly folded cubes. Only basic functional requirements addressed	Utilised more complex manufacturing processes and explored material potential.
Aesthetics unrefined and consideration of user comfort and safety not demonstrated	Superior aesthetics, clever stacking solutions and more cafe friendly designs
Lack of technical proficiency, demonstrating only a rudimentary knowledge of sheet metal manufacturing	Designs more technically proficient including sheet cutting patterns/ waste minimisation

Figure 6.8: Constrained project – outcomes and analysis
(Image source: student designs - final year engineering project)

Constrained project outcome examples – Mechanical Engineering students

The following three images (Figures 6.9, 6.10 and 6.11) portray typical Mechanical Engineering student outputs for the constrained (sheet metal chair) problem.

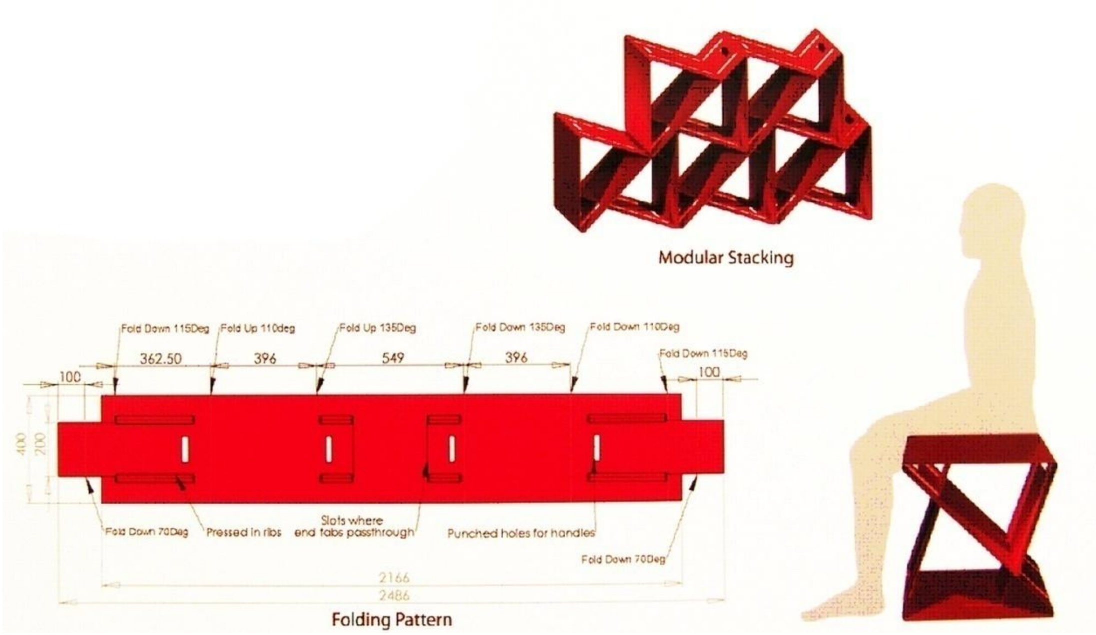


Figure 6.9: Mechanical Engineering student outcome 1.
Folded metal construction, with unresolved sharp edges. Stacking considered.
(Image source: ME student design - final year constrained project)

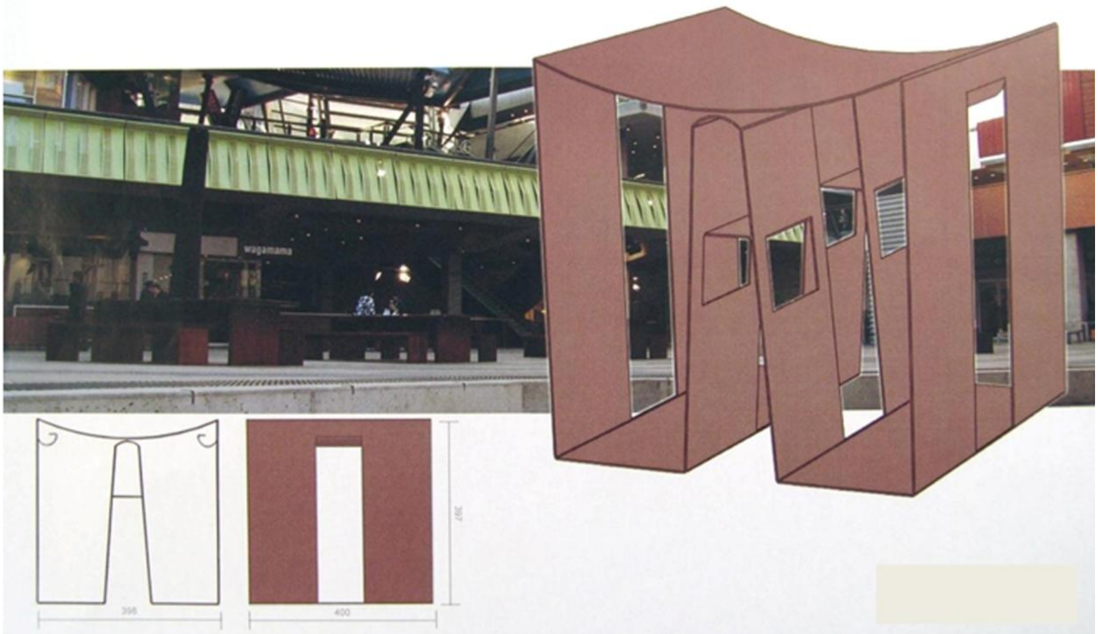


Figure 6.10: Mechanical Engineering student outcome 2
Stacking not considered, unrefined aesthetic form.
(Image source: ME student design - final year constrained project)

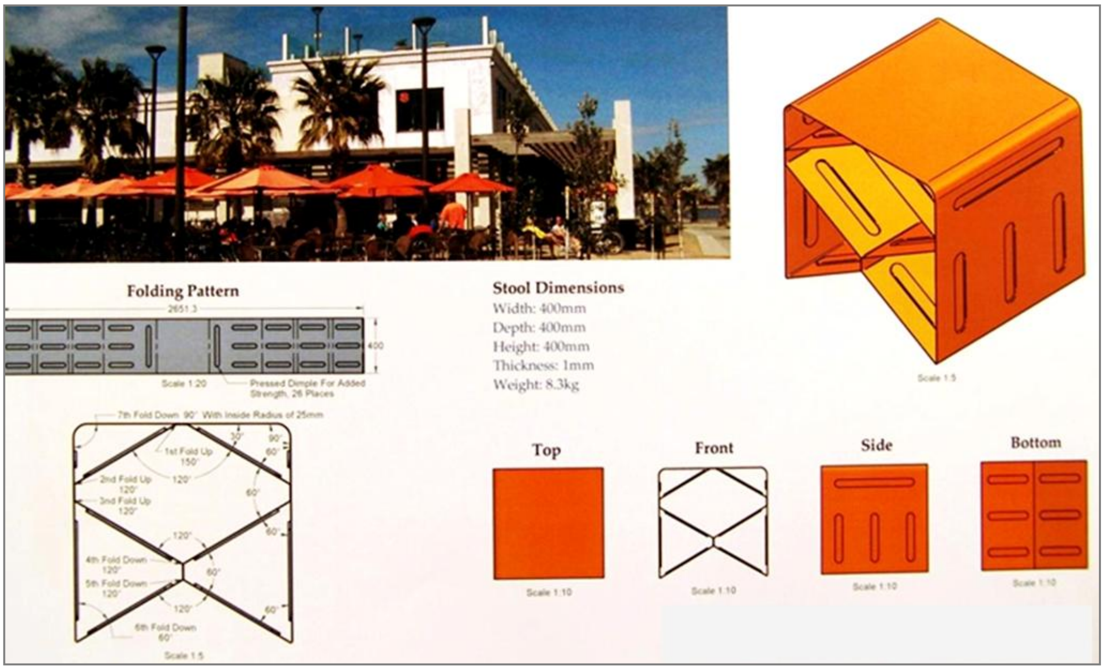


Figure 6.11: Mechanical Engineering student outcome 3.
The best ME student outcome, but stacking not considered and sharp edges exposed.
(Image source: ME student design - final year constrained project)

It can be seen from these examples that the Mechanical Engineering students were more comfortable with the constrained, technical project with all students achieving an appropriate design solution, although unfortunately most were simple folded variations of a cube structure with many forms quite 'two-dimensional.'

Once again user and environmental requirements were not well considered, with single thickness metal edges presenting a safety hazard, and stacking rarely addressed, even though it is a prime requirement for hospitality furniture.

The mechanical engineering students performed much better at the constrained problem with a level of familiarity with the design process that was not evident in the open-ended problem. However the ME students demonstrated only rudimentary knowledge of sheet metal manufacturing processes, limiting their potential to explore new and innovative forms, or resolve structural issues.

Constrained project outcome examples – Product Design Engineering students

The following images (Figures 6.12, 6.13, and 6.14) portray examples of Product Design Engineering outputs for the constrained (sheet metal chair) problem.

Figure 6.12: Product Design Engineering student outcome 1
Highly sculptural form with complex manufacturing and stacking resolved
(Image source: PDE student design - final year constrained project)

Figure 6.13: Product Design Engineering student outcome 2a
A sculptural and friendly form, with manufacturing sequences resolved
(Image source: PDE student design - final year constrained project

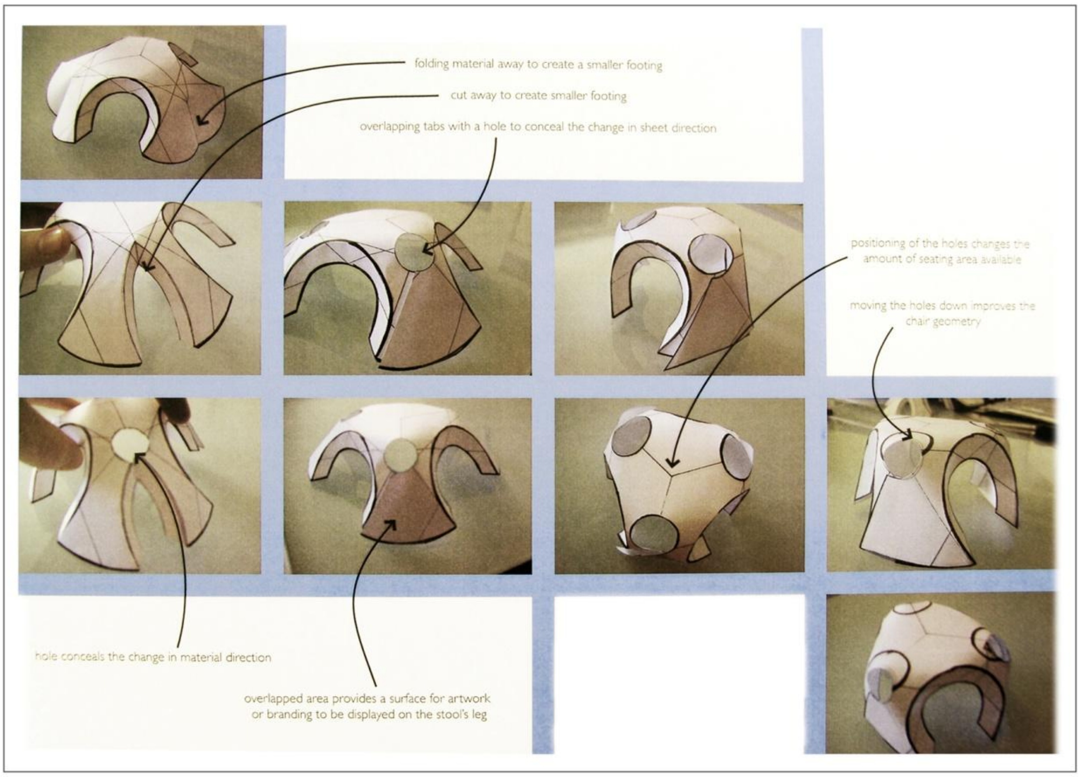


Figure 6.14: Product Design Engineering student outcome 2b.
A design development process utilising marquettes to resolve these complex forms demonstrates both vision and technical ability. (Image source: PDE student design - final year constrained project)

6.9 Student feedback

After the project students were asked to complete a retrospective survey addressing sketching and conceptualisation, problem-solving and overall project analysis.
The self-reflective survey found that the Mechanical Engineering students:

- were hindered by inability to articulate ideation through drawing,
- were more at ease and familiar with constrained problems, rather than open-ended or ill-defined problems,
- were uncomfortable with the short lead times of the project, and
- found the product design activity was unfamiliar territory,

whereas the Product Design Engineering students:

- were comfortable and confident with both open-ended and constrained problem-solving activity, and
- benefited from their sketching and design skills and experience in user-centred design.

The responses indicated that all students felt challenged by the projects, but thought that the problems posed were appropriate for their skills and knowledge. There was a general confirmation that students valued the experience, and wanted more solution-focussed and open-ended projects during their course.

6.10 Conclusion

The results of this study appear to support the initial hypotheses. As expected, the Product Design Engineering students performed better at the open-ended problem due to their familiarity with uncertainty, experience with user-centred design and established design abilities. Whilst it was predictable that ME students would lack drawing skills and design experience, it was expected that this would affect only the quality of their aesthetic design and presentation. It is apparent however, that it also affected the quality and diversity of their ideation and subsequent reflective practice. These students, although technically competent, were relatively inexperienced in applying their engineering knowledge to a project that required a product design outcome. The lack of formal design training manifested in the early problem framing stages with poor analysis of the problem, infrequent consideration of user needs and environment, and poor design exploration and product resolution.

In the open-ended project, whilst all the PDE students had successful and well considered outcomes, the ME students did not move beyond poorly executed iterations of an existing product. To a certain extent it had been anticipated that the open-ended problem may not suit the MEs. However the constrained and more technical project with its application of manufacturing and material knowledge was expected to produce more even results between the student cohorts. Unfortunately it did not. Whilst all of the students produced satisfactory results for the constrained problem, once again the solutions of the PDE students were superior; aesthetically, functionally and in technical resolution for manufacture.

This is not to say that the Mechanical Engineers are poorly prepared for industry, but rather that the specific design skills (user-centred design, creativity, open-ended problem definition etc), required for new product development were absent.

Contrary to expectations, the multidisciplinary Product Design Engineering students proved to be more adept at engineering design due to their ability to apply their science in practice. In this evaluation they were found to be significantly better at problem framing and technical resolution, in a product context, than the other student engineers, even when faced with constrained and more technical problems.

This clearly demonstrates that the inclusion of 'designerly ways' into the engineering curricula has not compromised the integrity of the 'science' of engineering. Rather it has enhanced the 'practice' through the addition of new skills and new ways of thinking. Consequently it can be surmised that the PDE curriculum is achieving its aim to develop engineers who are more suited to roles in new product development.

6.11 Discussion

Industry feedback suggests that engineering graduates are often 'unsuitable' for employment in product design roles because of 'skill deficiencies' in creativity, problem-solving, and independent and critical thinking. (Cropley and Cropley 2000) Fostering creativity may not be occurring or may be ineffective and the language of mathematics is taught rather than the language of design. (Dym 1999)

The initial findings of this ongoing comparative evaluation of the problem-solving skills of engineering students, whilst derived from a relatively small sample group, support the 'educational justification for design' (Cross 2001) as a means to develop real-world problem-solving abilities.

The mechanical engineering students were found to be adversely affected by their under-developed creativity and open-ended problem solving ability as noted by Cropley and Cropley (2000) in their study of engineering undergraduates. There is clear evidence from this limited study that engineering students intending to work in new product development need to develop greater aptitude in problem solving as suggested by Grasso and Martinelli (2007).

Engineering curricula must develop creativity and design aptitude, if we are to graduate engineers who are more than just technically competent. It is apparent that sketching and design activities, and experience in the practice of engineering can be a motivating factor in engineering learning developing more creative and adaptive design engineers.

Experience with poorly-defined design problems that are not amenable to the 'techniques of science and engineering' (Cross 2006), is invaluable in engineering education. Open-ended design problems force students to think creatively and appreciate creative solutions (Ghosh 1993), become comfortable with divergent thinking processes and develop ideational fluency. It is essential that students develop flexible and divergent dichotomies and eliminate tendencies to fixate on existing solutions if they are to be prepared for roles in new product development.

The Product Design Engineering model appears successful in producing creative and adaptable design engineers who are comfortable with poorly defined problems and the design of unprecedented product solutions. These are graduate attributes that are valued in new product development industries.

Chapter 7: Graduate skills and career pathways

7.1 Overview

This chapter analyses and interprets the responses from the 2010 survey of the Swinburne Product Design Engineering alumni. This confidential on-line survey asked graduates to respond to questions relating to:

- securing employment,
- current roles and responsibilities,
- career progression,
- the most career beneficial aspects of the course,
- differentiation in graduate skills and attributes between disciplines,
- potential curriculum improvements/inclusions, and
- the impact of low recognition of the PDE discipline on their careers.

The results indicate high graduate satisfaction with their educational journey and graduate attributes, and the establishment of strong career pathways. The results also confirm the success of the new engineering discipline of Product Design Engineering.

The findings of this survey, in conjunction with the curriculum benchmarking exercise detailed in Chapter 2 and the assessment from industry through employer interviews in the following Chapter 8: *Industry Relevance*, validate Product Design Engineering as a viable alternative to the employment of industrial designers and mechanical engineers for roles in new product development.

7.2 Introduction

Early chapters of this thesis have identified key graduate attributes for engineers engaged in new product development (NPD), and discussed the curriculum development of these skills and knowledge in detail. Industry readiness requires an interdisciplinary framework of robust engineering and design acumen. Creativity, aesthetic styling, a user-centred approach, technical and manufacturing knowledge, and ill-defined problem solving skills are all expected attributes.

In 2010 an on-line survey was conducted amongst the alumni of the Swinburne Product Design Engineering program to examine graduate career pathways, employment industries, and roles and responsibilities. It aimed to identify the most valuable aspects of the curriculum, determine workplace expectations of Product Design Engineers and asked alumni to compare their skills and abilities with those of their NPD colleagues, i.e. mechanical engineers and industrial designers. Also examined was the impact of poor discipline awareness, in industry and community, and the lack of professional recognition for Product Design Engineering as a distinct engineering discipline.

7.3 The data collection process

This research was conducted in accordance with the requirements of the Swinburne University Human Research Ethics committee, who granted approval on 16 April 2010 for a 'Survey of Product Design Engineering Graduates' (Ethics Clearance No. SUHREC 2010/038).

The 2010 Swinburne PDE Alumni Survey utilised the Opinio survey software application to develop and implement an on-line survey comprising qualitative, quantitative, multiple choice and direct response questions. The fourteen question survey (available at Appendix 2) aimed to understand the new engineering discipline of Product Design Engineering, and the effectiveness of the curriculum (with regard to skills and knowledge alignment) from the perspective of graduates employed in relevant industries.

Survey invitations were issued by email and through professional social networking website LinkedIn, to ninety-eight Swinburne PDE Alumni for whom contacts details were available. The invitee group represented more than half of Swinburne Product Design Engineering graduates (from all graduating years), employed in a wide range of industries. As such the invitees represented a significant cross-section of the professional PDE community in Australia and accordingly, a valid survey group.
As the survey invitees covered nine graduating years, consideration was given in the sampling strategy with regard to the alumni's ability to respond to the survey without predisposition or bias. It was expected that more recent graduates would be closer to the current course structure and teachers, and as junior staff could only provide input with reference to their current role. However those in more senior positions, whilst more detached from the educational process, could confidently provide a broader industry perspective.

The survey of PDE alumni resulted in both quantitative and qualitative data, some of which could be considered highly subjective. In some instances a sensitivity analysis was necessary as in the case of sustainability and social responsibility where the responses of students who graduated prior to these curriculum inclusions reflected a different understanding and methodology. The validity of the alumni claims and the resultant research findings require ratification by comparison with independent observation by industry employers. This verification occurs through semi-structured interviews with employers of PDE alumni (in Chapter 8: Industry Relevance).

7.4 Response to survey

Fifty-eight Swinburne PDE Alumni responded to the survey. This represented sixty-three percent of invited applicants, a good response ratio. Most importantly, all graduating years (2001 to 2009) were represented with at least four students, as is evident in Figure 7.1. This was crucial to ensure a result that reflected the full spectrum of teaching approaches since the course's inception in 1997, and to identify long-term characteristics. Respondee gender balance was 76 percent male, 24 percent female. This is highly representative of the overall PDE community, as Swinburne

PDE graduate gender ratios have averaged approximately 24 percent female since course inception.

However, there was an imbalance of responses with the 2008 graduating year being significantly over-represented, and resultantly closer to the current curricula; however the consistency of responses across the whole sample group appears to indicate that this group did not unduly influence the findings.

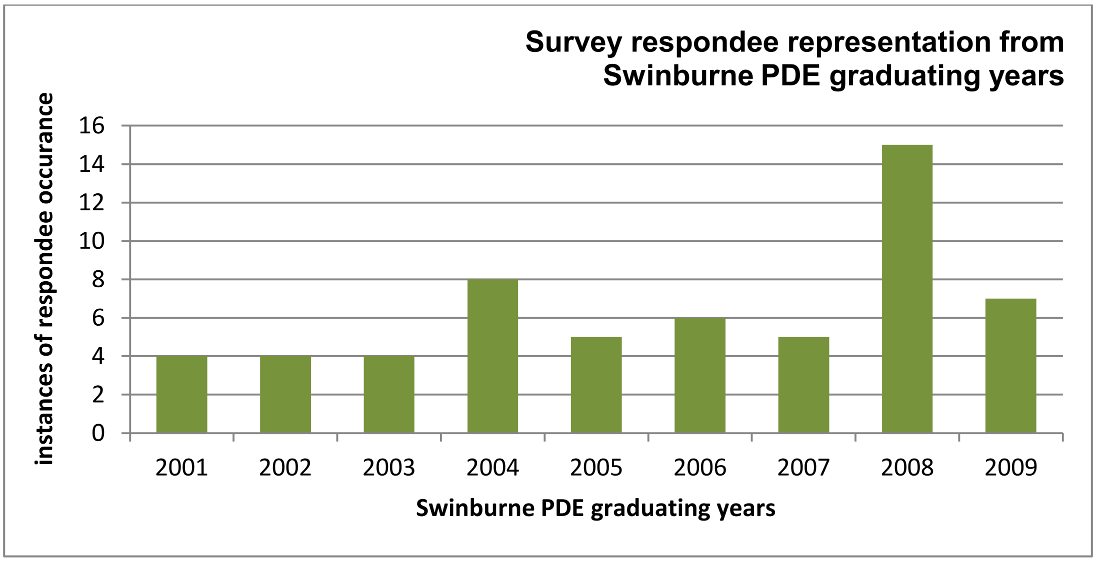


Figure 7.1: Distribution of respondees to PDE Alumni Survey represented by graduating years (data source: PDE Alumni Survey 2010)

7.5 Current employment

The survey asked respondees to state their current employment role, employer industry and areas of responsibility. This question aimed to define what percentage of PDE graduates gained employment in Product Design Engineering related positions, whilst role seniority and levels of responsibility were useful as indicators of career progression.

7.5.1 Employment in relevant fields

Of the fifty-seven respondees, forty-nine (86 percent) indicated that they were directly employed in Product Design Engineering positions across a wide range of industries. Although role titles were varied and included Product Designer, Product Engineer, Product Design Engineer, Designing Engineer, Senior Design Engineer, Senior Product Engineer, and Product Design Consultant, for the purpose of this analysis they were all considered to be engaged in Product Design Engineering.

As shown in Figure 7.2, a further five respondees (9 percent) were employed in related industries/fields, two respondees were in unrelated industries and one was unemployed.

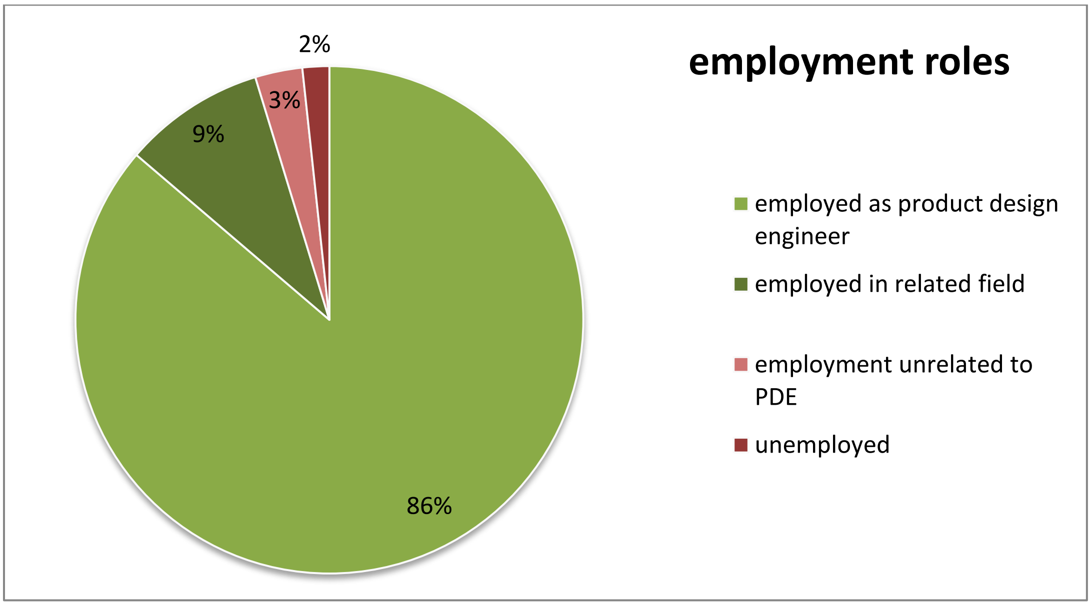


Figure 7.2: Alumni employment roles
(data source: PDE Curriculum Benchmarking Survey 2010)

This data clearly shows that the overwhelming majority of Swinburne PDE graduates achieve employment in their chosen profession, with 95 percent either employed as Product Design Engineers, or in related fields. Those employed in relevant fields include:

- a Patent Attorney (in the field of mechanical engineering and design),
- a Product Manager in the mining industry,
- a Research Fellow in an Eco-Design lab,
- a Systems Scientist (mining industry), and
- a CEO of a sustainable transport company.

For the purpose of this survey analysis these roles were considered to be in 'related fields' as these graduates have responsibilities that require them to use their skills and knowledge from their PDE education in the course of their daily duties.

7.5.2 Employment industries

Figure 7.3 shows the breadth of industries in which the surveyed alumni of the Swinburne Product Design Engineering program have gained employment.

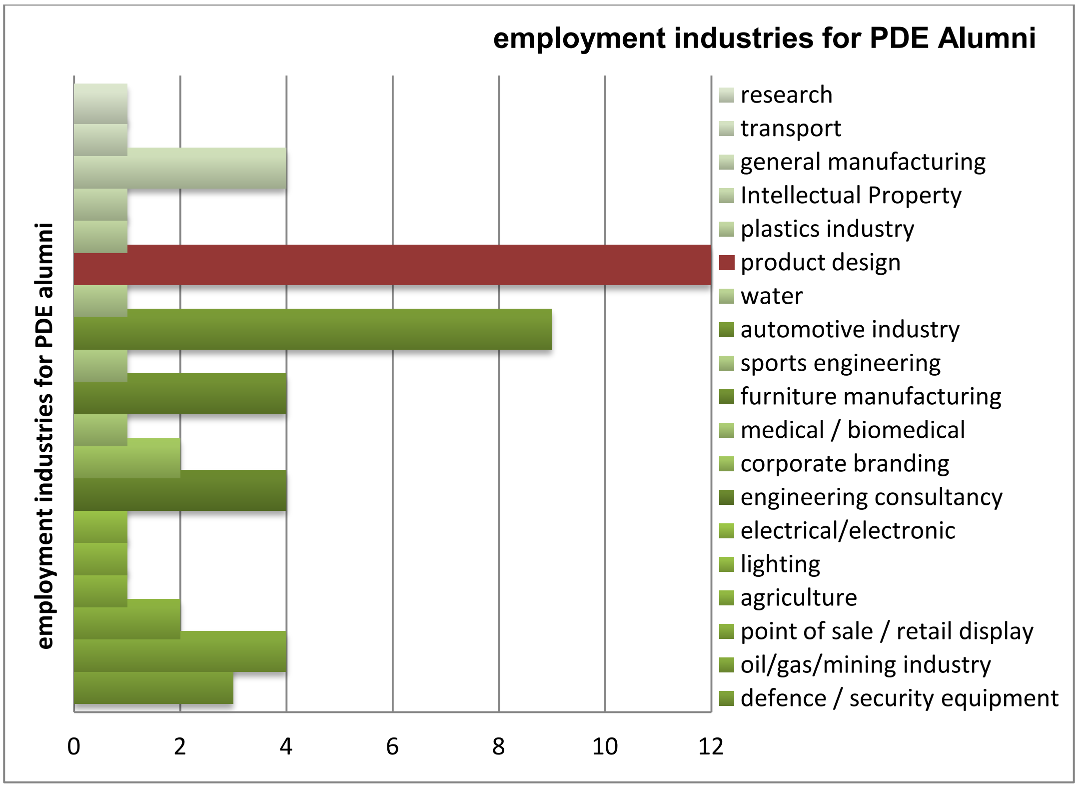


Figure 7.3: Employment industries for PDE Alumni
(data source: PDE Curriculum Benchmarking Survey 2010)

There is significant employment diversity with graduates working in a wide range of industry positions ranging from water purification to point-of-sale display, automotive engineering to furniture design, bio-medical design to lighting manufacture, and general manufacturing to intellectual property protection. However for ease of reference, the different employment industries have been grouped into industry 'sectors' as shown in Figure 7.4.

Melbourne is the manufacturing base of Australia, with three automotive manufacturing plants and many associated industries. Accordingly, it is not surprising that 17 percent of alumni are employed directly into the automotive industry and 20 percent are employed in other manufacturing industries as shown in the sectoral representation in Figure 7.4.

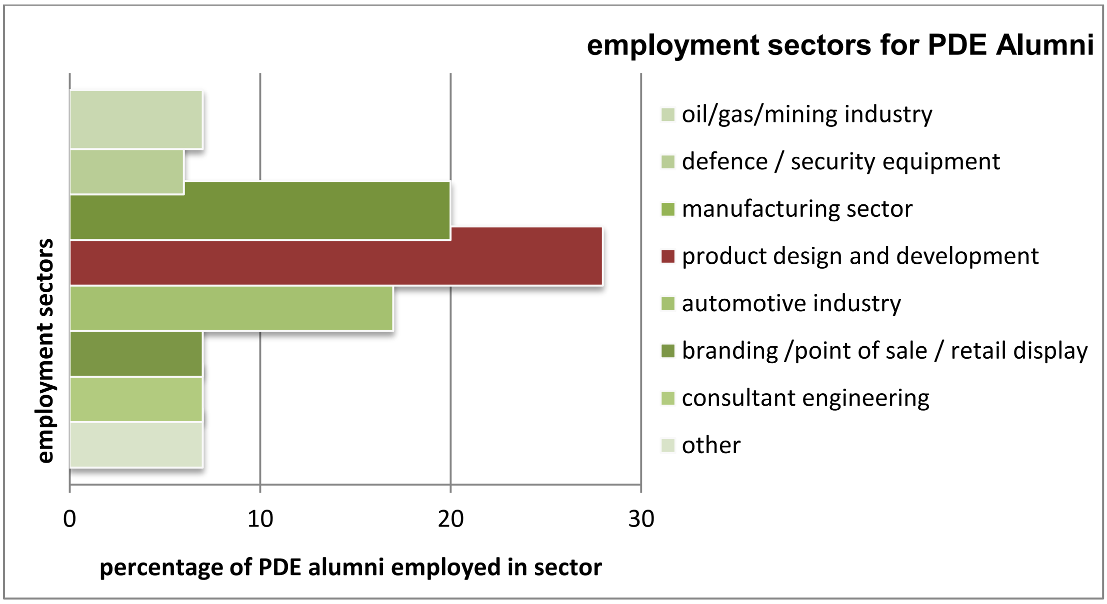


Figure 7.4: Employment sectors for PDE Alumni (condensed)
(data source: PDE Curriculum Benchmarking Survey 2010)

What is immediately apparent is the prevalence of PDE alumni employed in product design and development, mostly in design consultancies. This is a sector of Melbourne industry where PDE has had a substantial impact. Prior to the emergence of Product Design Engineering as a new discipline, the product design sector predominately employed industrial designers and utilised the services of mechanical engineers as appropriate. Now all the major product design consultancies employ a number of PDE alumni, and increasingly use them, not just for product engineering but from ideation through to design embodiment and resolution for manufacture.
It is evident that this employability, driven by the breadth of skills and multidisciplinary knowledge base, is one of the strengths of the Product Design Engineering discipline. Graduates appear to secure suitable employment relatively quickly after graduation, their versatility and cross-discipline skills value by employers in all industry sectors.

The industries which employ Swinburne PDE alumni are similar to the industries identified by global PDE program coordinators as the main employment industries for their graduates. Figure 7.5 shows the five main industry destinations for PDE graduates with the Swinburne PDE industries (in red) overlaid over global PDE employment. It is evident that PDE graduates for all courses are employed in similar industries; product design and development (or NPD), manufacturing, engineering design, automotive and production engineering being the most common. More Swinburne PDE graduates gain employment in automotive industries than other PDE programs, this most likely due to the Melbourne industry being dominated by three major automotive manufacturers and the associated supply industries.

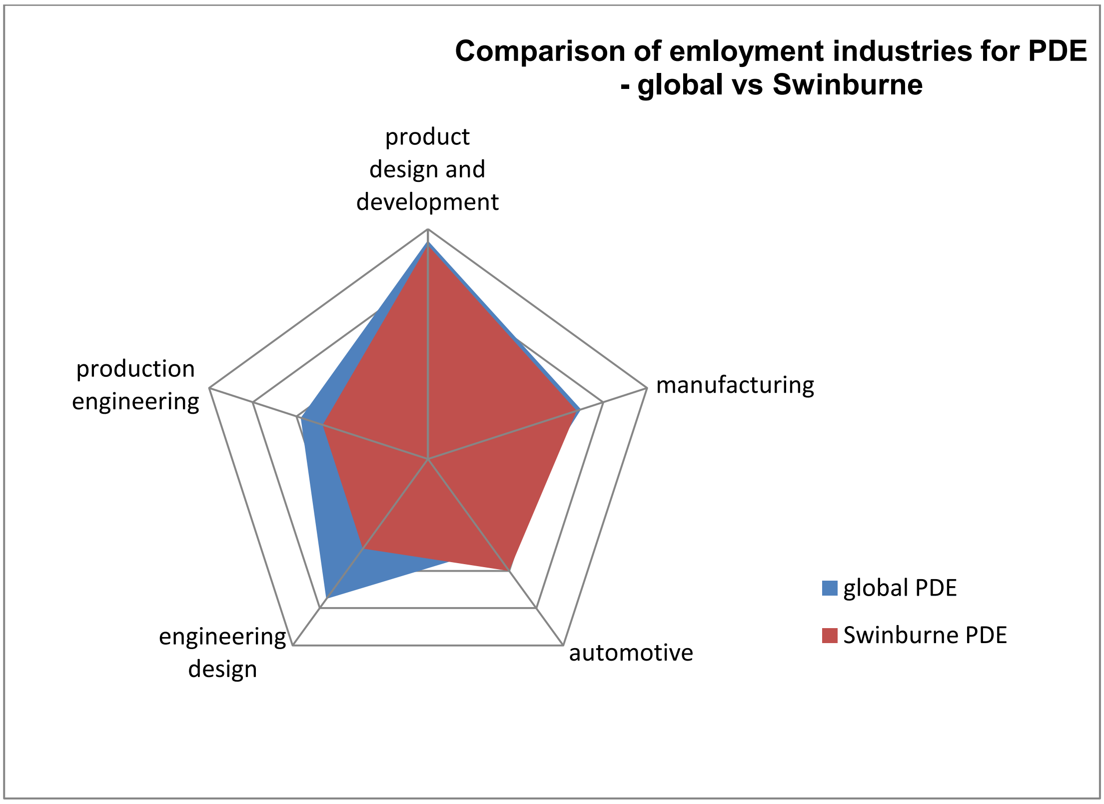


Figure 7.5: Comparison of employment sectors for PDE - global vs Swinburne
(data sources: PDE Curriculum Benchmarking Survey 2010 and PDE Alumni Survey 2010)

7.5.3 Time to secure employment

Product Design Engineering graduates appear in demand, with industry actively recruiting at end-of-year graduate exhibitions and students quickly securing employment. Industry employers are well represented on the Course Advisory Committee and engaged in delivery of the curriculum through sessional lecturing roles and involvement in industry-led projects. This is often an ideal way for employers to identify and secure talented students prior to graduation.

This is evident in the 'time to secure employment' statistics. Figure 7.6 shows alumni employment data for a nine year period, from the first graduating year of 2001, through to 2009.

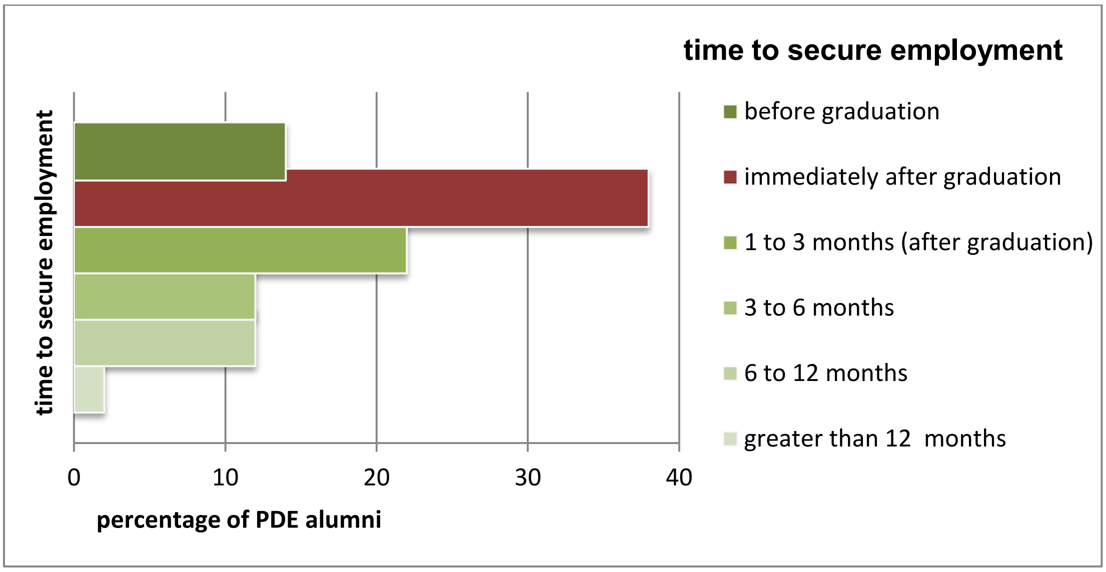


Figure 7.6: Time duration before securing employment (post graduation)
(data source: PDE Curriculum Benchmarking Survey 2010)

14 percent of the alumni surveyed said they had secured employment *before* they completed the course, 38 percent employment gained jobs immediately upon graduation, and 22 percent secured employment within three months. Overall, 74 percent of graduates were employed in their chosen industry within three months of completing the Product Design Engineering course at Swinburne.

These statistics indicate a very high level of industry acceptance for this new engineering paradigm from the first graduates to the most recent. An indication of the industry relevance of the Swinburne PDE curricula is that whilst graduating students' numbers have grown significantly during this period, industry demand has also increased sufficiently to maintain both high employment rates and the quick uptake of PDE graduates, post graduation.

It is apparent that the PDE graduates possess skills and attributes that make them highly employable by local industries. This is also reflected in the professional roles and responsibilities, and career progression of alumni.

7.5.4 Roles and responsibilities

A detailed analysis (refer Figure 7.7) of the current roles and responsibilities of Swinburne PDE alumni reveals that although there is diversity of positions and roles, several strong trends are evident.

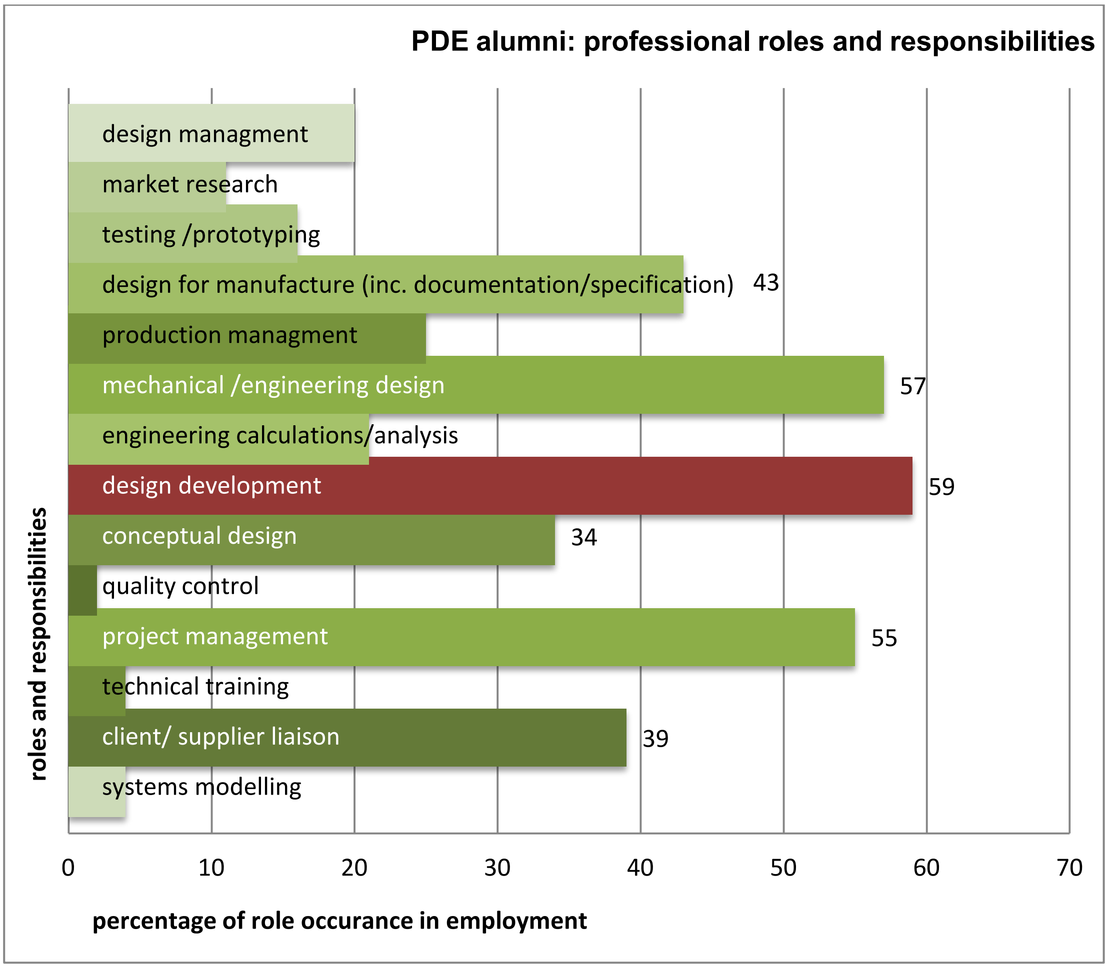


Figure 7.7: Professional roles and responsibilities for PDE alumni
(data source: PDE Curriculum Benchmarking Survey 2010)

The main areas of professional activity are not unexpected, these being typical roles for any engineer engaged in product design and development. Design development is the most common activity involving 59 percent of graduates, closely followed by mechanical design / engineering design (57 percent) with design for manufacture occupying 43 percent of alumni.

More interesting are the figures for:

- conceptual design (34 %),
- project management (55%), and
- client and supplier liaison (39%).

One third of Product Design Engineering graduates are engaged in front-end product ideation; roles typically the domain of industrial designers. It is expected that this is in direct response to the multidisciplinary nature of PDE graduates and the design training that is embedded within the curriculum. Whilst several employers had indicated that they used PDEs in creative conceptual roles (refer Chapter 8), the survey data reinforces new roles and responsibilities for these engineering graduates.

The multidisciplinary nature of the PDE curriculum also benefits graduates in project management and client liaison roles. More than half (55 percent) of the PDE alumni list project management as a main role, with many commenting that their understanding of, and skills in, both disciplines enabled them to see the 'big picture' making them ideally suited for management and liaison roles. One alumnus commented that his 'cross-over of skills' enabled him to have a "better understanding of reality, a better understanding of real world issues, including the ramifications of design decisions."

39 percent of PDE alumni said they were involved in client and supplier liaison, however it should be noted that the actual figure for this role is probably higher, as roles were only recorded where the respondee explicitly mentioned that activity. It is likely that anyone engaged in project management is also engaged in such liaison, but this was not included in client liaison figures without specific notification.

7.6 Most valuable skills

The PDE Alumni Survey asked graduates "what aspects of the PDE course have been the most valuable in your career?"

Respondees could answer with multiple selections from a supplied list of nine pre-selected answers, and they were given the opportunity to input individual qualitative responses. The question aimed to identify specific areas of the curricula that had the most relevance to their professional activities. Figure 7.8 highlights those curriculum areas considered most valuable.

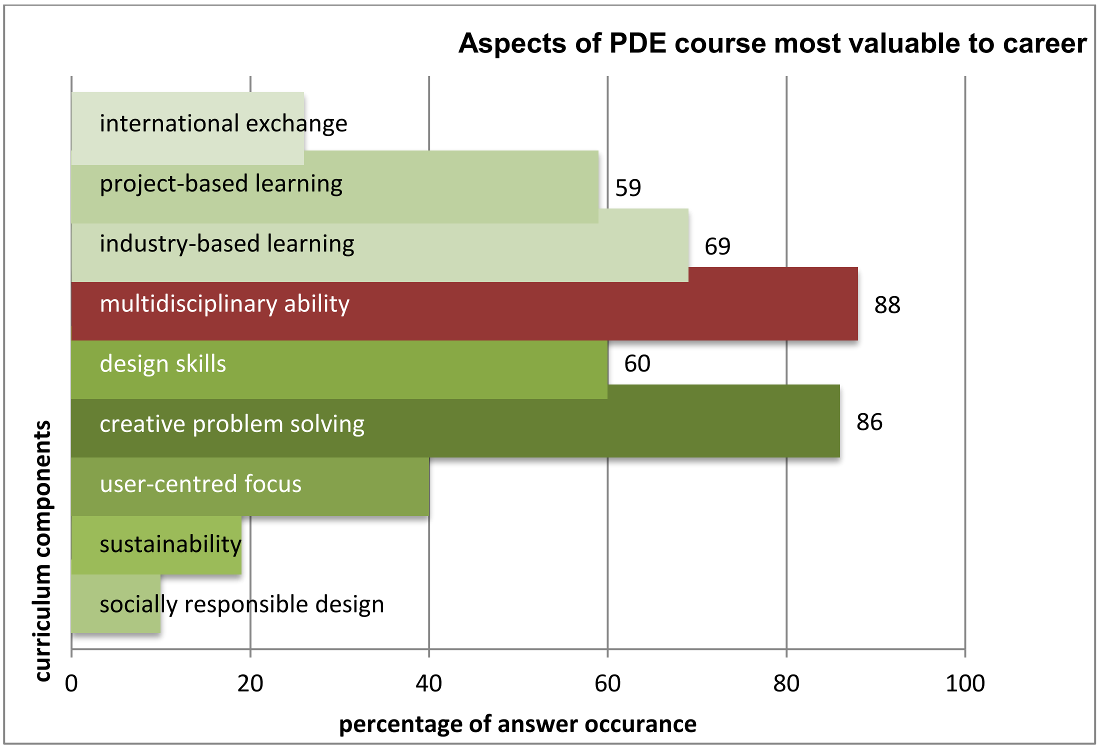


Figure 7.8: Aspects of PDE course most valuable to alumni careers (data source: PDE Curriculum Benchmarking Survey 2010)

88 percent of alumni nominated 'multidisciplinary ability' as the curriculum component most valuable to their career, closely followed by 'creative problem solving'. The curricula emphasis on 'project-based learning' (59 percent), the development of 'design skills' (60 percent) and user-centred design (40 percent) were also highly ranked, with alumni singling out these variables as distinctive elements of the PDE course, relatively uncommon in engineering programs, but as identified in Chapter One, essential for new product development roles.

Also valued highly by alumni was Industry Based Learning (IBL) where students are placed in paid industry internships for six to twelve months before the final year.

Less highly ranked were two current curricula agendas:

- sustainability (19%), and
- socially responsible design (10%).

Whilst this result was unexpected, considering the importance of these agendas in engineering education, further analysis revealed that the more recent graduates undertook specific design subjects entitled:

- HDPD224 Sustainable Design (in second year), and
- HDPD324 Socially Responsible Design (in third year).

However, alumni who completed the course prior to the course reaccreditation and restructure which was introduced in 2006 had no formal instruction in these areas, so did not select these options. As the response from alumni was fairly evenly split between alumni who completed prior to 2006 (30 responses), and post 2006 (28 responses), consequently the data can be reinterpreted to reflect only the responses from those post 2006 graduates.

As only 48 percent received specific training in sustainable design and socially responsible design, the adjusted responses from post-2006 alumni are as follows:

- sustainable design (39%), and
- socially responsible design (21%).

These reinterpreted figures, whilst more accurate and a better reflection of the educational agendas prevalent in the PDE curriculum, are still somewhat low. It is apparent that many graduates are not involved in socially responsible design and hence do not value this curriculum component at this stage of their career. It can also be deduced from the relatively low numbers who value their sustainable design education (less than half), that these graduates who are in the early stages of their career, are not in a position to fully utilise their knowledge of sustainability in their professional activities. As education in critical societal agendas is a long-term plan one hopes that in future, these graduates will be called upon to use their skills in sustainable design as industry responds to market and legislative pressures.

Additional text-based responses were provided by a third of the survey respondees. Although there was a range of specific aspects of the course that had proved valuable to the Swinburne PDE alumni, several common themes emerged as follows (in order of frequency of response):

- integration / early consideration of engineering knowledge in design process,
- communication skills,
- presentation skills,
- challenges and work ethic,
- project management,
- team work skills,
- preparation for industry,
- understanding the whole NPD process,
- knowledge of technologies, materials and processes,
- ability to deal with ambiguity in problems, and
- sketching ability.

From these responses it appears that the goal of the PDE curriculum to develop well-rounded, interdisciplinary engineers for employment in new product development has been successful. All areas of the PDE curricula have proved valuable in the alumni's employment, with the key areas of multidisciplinary approach and creative problem solving most valued.

Although individual graduates valued different aspects of the curriculum, this was reflective of the role and industries in which they were employed. It is noteworthy that not one of the fifty-six respondees had negative comments regarding the Swinburne PDE curriculum.

7.7 PDE compared with Industrial Design and Mechanical Engineering

The Swinburne PDE alumni were asked to identify distinguishing characteristics of Product Design Engineers, and also to make distinctions between their skills and attributes in comparison with those of mechanical engineers or industrial designers. It must be noted that the following self-analysis and the comparisons made by the alumni in this section (and in the following section 7.8), are by nature highly subjective and therefore need to be ratified by industry employers; this occurs in the following Chapter 8; *Industry Relevance.* However as the Swinburne PDE course is unique in Australia, it is interesting to understand how alumni define themselves as a professional discipline, and view their contribution to new product development environments.

7.7.1 The distinctive characteristics of PDE

The PDE alumni identified shortcomings of both industrial designers and mechanical engineers in the new product development environment, highlighting their multidisciplinary ability as one of their principal strengths. Most respondees commented on the lack of breadth of the other professions, and the PDE's ability to work more broadly, balancing aesthetics, user and technical needs and manufacturability. The ability to understand and input across the whole product design and development process is seen by the PDE alumni as their most important contribution, as is evident is the following responses in which they note their distinctive skills and attributes:

> "creative *and* technical problem solving abilities."

> "the ability to combine both skill sets and use them together..."

> "ability to combine creative and technical thinking to produce holistic solutions."

> "multidisciplinary ability allows greater meaningful professional interaction with a wide range of people throughout the design process and production."

> "the ability to understand the fundamentals of disciplines, allowing me to approach a design or engineering problem from both sides."

> "multidisciplinary ability, a broader view of product design as a whole."

> "ability to consider design *and* engineering interaction in projects"

> "practicality and unbiased design approach."

> "unique problem solving/design approach, innovative, out of box thinking which incorporates holistic view on product design/solutions."

> "greater ability to see further into a project while designing at the front end."

> "a broader scope of thinking in project planning and problem solving."

The PDE alumni were also consistent with regard to the contribution of their multidisciplinary approach to the product design and development process and consequent design outcomes:

> "the ability to combine style, usability and ease of manufacture, satisfying clients with a marketable product that is more cost effective."

> "marrying aesthetics, ergonomics and ease of manufacture."

> "being able to merge and *enhance* the aspects of aesthetics, user centred approach and functionality regardless of type of product or project."

> "understanding reasons behind design or styling wants and finding solutions to meet the wants that are manufacturable."

> "being able to see a marketable solution to an engineering problem."

> "ability to develop products that consider more of the key stakeholders, and get product to market quickly in a form closer to the design intent."

> "(PDE's) holistic view on product design/solutions distinguishes them from the Mechanical's conservative, traditional approach which tends to base solutions on existing problems."

> "ability to apply engineering knowledge to influence and ensure good design solutions rather than limit or restrict them."

It is apparent that the Product Design Engineers see themselves as 'intermediaries' with the ability to 'do the job of both professions' but with a 'unique problem solving and design approach,' who consider all aspects simultaneously, and collaborate more effectively across discipline boundaries. Many commented on their ability to contribute to cost-effective product production, without compromising the original design intent. For a relatively new professional engineering discipline, what is immediately apparent is that PDE alumni possess:

- strong self belief and understanding of their contribution to product design,
- strong cross-disciplinary skills and communication ability,
- certainty in their ability to improve product development processes, and
- a synergetic approach that balances aesthetic and technical, marketing, manufacturing; customer needs, function, style and production.

7.7.2 Identifying the differences between PDEs and Mechanical Engineers

Product Design Engineers work closely with both industrial designers and mechanical engineers in the workplace, and in some instances, replace both disciplines. As the PDE curriculum is derived from an integration of these disciplines, it is interesting to compare how the PDE graduates differ from their single-discipline colleagues.

The PDE alumni identified several key differentiators where they had distinct skills and knowledge from mechanical engineers:

- creativity,
- user-centred design,
- design skills (sketching, aesthetics, styling),
- market understanding,
- maintaining the design intent (through to production), and
- preparation for industry.

(a) Creativity

As products of a curriculum that strategically fosters creativity throughout the four-year program, the PDE alumni believe that creativity is one of their core strengths and a key skills differentiator between them and mechanical engineers:

> “(PDEs have) the ability to think creatively for concrete problems.”
>
> “Mechanical engineers tend to carve up projects into discreet 'boxes' limiting creative opportunities and losing the overall design vision.”
>
> “(PDEs have) a unique problem solving/design approach, innovative ‘out of the box’ thinking.”
>
> (PDEs are) a lot more creative than mechanical engineers.”

(b) User-centred design

The PDE curricula focus on user-centred design was seen by the alumni as a key distinguishing characteristic between PDE and mechanical engineering alumni:

> "(MEs lack skills) in user-centric design, ergonomics."

> "(PDEs are) less 'blinkered' than mechanical engineers, and perhaps more willing to collaborate across different disciplines to achieve more user-centred solutions."

> "(PDEs employ) a user centred approach for a 'complete' product design."

> "PDEs understand customer needs."

(c) Design skills (sketching aesthetics, styling and ideation)

The integration of design skills into engineering education has resulted in PDE graduates who are confident in their ability to sketch and ideate, maintain product aesthetics throughout design development and manufacturing resolution and to influence and direct good design solutions.

> "PDEs have the design skill to still make beautiful, but functional products -not just technical knowledge."

> "(The PDEs ability) to sketch and express ideas quickly and accurately is a very important and useful skill to have."

> "Mechanical engineers struggle to develop 'blank sheet' products."

> "(PDEs have the) ability to apply engineering knowledge to influence and ensure good design solutions rather than limit or restrict them."

(d) Market understanding

The PDE curricula approach to product design appears to provide alumni with clear understanding and consideration of market and user needs and commercial concerns:

> "PDEs understand the need to achieve commercial viability."

> "MEs don't understand trends in design, part form and product positioning."
> "(PDEs are) able to see a marketable solution to an engineering problem."

(e) Maintaining the 'design intent'

Many of the PDE alumni stated their ability to develop and resolve product technical, functional and production aspects, without compromising the original design intent. The inference was that the MEs lack of design acumen may compromise the design, from an aesthetic or marking perspective, during production resolution.

> "(PDE have) the ability to strategise, develop and maintain the design's aesthetic integrity right through production and end use."

> "being a 'middle man' between the two to ensure the least compromise moving from a concept through to a production-ready design."

> "Able to understand the intent of a sketch, interpret and then implement it into CAD more accurately (than a ME)."

(f) Preparation for industry

The project-based learning model, with industry-led projects, adopted by the PDE curricula appears to have thoroughly prepared the Product Design Engineering alumni for roles in new product development industries:

> "As a graduate I was better at everything than the Mechanical Engineer equivalent. It was only after actual, real world project experience that the Mechanical Engineers came up to speed."

(g) Observation

It should be noted that the comparative analysis of PDE and ME skills by the Swinburne PDE alumni whilst focussed on the needs of new product development roles, does not consider deep technical skills such as detail design, engineering analysis and scientific knowledge where ME graduates are considerably more experienced and possess a deeper level of consideration and critical rigour. Whilst it is not unexpected that a relatively new discipline will seek to highlight its own credentials, self-analysis must be tempered through workplace feedback from their employers.

7.7.3 Identifying the differences between PDEs and Industrial Designers

The survey answers indicate that the PDE alumni are less competitive with the industrial designers, than they are with their mechanical engineering colleagues. However they were consistent in their comparisons of their skills and expertise with those of the industrial designers in their workplace, but ignored areas where Industrial Designers would be expected to have greater proficiency such as front-end skills (e.g. creative ideation, concept sketching).

The PDE alumni identified five key differentiators where they had distinct skills and knowledge from industrial designers:

- technical knowledge,
- manufacturing knowledge,
- project management skills,
- engineering analysis and calculations (outside industrial design training), and
- multidisciplinary ability/ broader scope of practice.

As per the comparisons with mechanical engineering, the Swinburne PDE alumni identified their broader scope of operations (as multidisciplinary designers/engineers) as enhancing their understanding of, and contribution to, the product design and development process.

(a) Technical knowledge

Lack of technical knowledge is a recurring theme when people discuss the skills of industrial designers in a product design and development context. The PDE alumni's comments reflect the views of industry employers (in Chapter 9) and PDE program coordinators worldwide (Chapter 3):

> "I've worked with a few industrial designers and have found that they lack basic technical knowledge. If an industrial designer was to take on my position, I don't feel that they would have the technical understanding of how pieces are manufactured and put together, to be able to run calculations on pieces to support the design, nor produce fabrication drawings that are necessary for quoting and manufacturing."

"(PDEs have) the ability to apply engineering knowledge to influence and ensure good design solutions."
"IDs lack complex mechanical knowledge and understanding."

"(PDEs have) the ability to design as an industrial designer, *but* with mechanical methodology and principles.

"Compared to an industrial designer, we (PDE) possess the technical knowledge to take a product from concept to manufacture; we know what will work and what won't."

(b) Deeper knowledge of manufacturing process

Their technical knowledge and broader understanding of material and manufacturing processes was highlighted by the Swinburne PDE alumni as a major strength, when compared to industrial designers:

"IDs do not get the same manufacturing technology experience."

"A broad knowledge base (in produce development and manufacture) developed throughout the course, gives PDE graduates a head start or advantage over industrial design and mechanical engineering graduates who would learn a lot of what is taught in PDE through employment experience."

"Our understanding of manufacturing processes ensures product development proceeds effectively and efficiently."

"(PDEs are) more production focused than an industrial designer through a deeper understanding of technical complexities, manufacturing constraints and therefore what is actually achievable."

"(PDEs have) a more 'cradle to cradle' approach to design. More focus on design for manufacture, and the 'manufacturability' of a design. Something that will look good, but also have the functionality to back it up."

"PDEs have the ability to understand design for manufacture from an early stage in a project. Industrial designers can struggle to get things working properly mechanically, and don't have a good grasp of production techniques and processes."

"In general we tend to have a deeper understanding of manufacturing processes compared to Industrial Designers."

(c) Engineering calculations / engineering analysis

One of the more apparent characteristics of the PDEs, compared to industrial designers, is their engineering qualification and subsequent ability to examine, analyse and validate a problem from an engineering or scientific perspective.

> "The obvious attribute that we posses over industrial designers is that we are certified engineers, that is, we have the ability to prove the engineering concepts behind the design and sign off the drawings etc."

> "(PDEs have) the ability to communicate effectively with engineers."

> "Compared to some industrial designers we can think through different stages and steps in a dynamic system and pick up on potential issues."

(d) Project management

The ability to effective manage product design projects was highlighted as a key PDE strength in comparison with industrial design, with the alumni stating:

> "IDs do not get the same project management training."

> "(IDs lack) project management skills!!!"

> "(PDEs are) able to macro manage & micro manage projects because of a vast range of knowledge in different fields."

(e) Multidisciplinary ability/ broader scope of practice

The ability to design with engineering understanding has resulted in a broader scope of practice for Product Design Engineers, and a cross-discipline approach:

> "Project planning & problem solving – (PDEs have) a broader scope of thinking."

> "Cross communication and project management stills. Having experience with working in both areas simultaneously. This makes multi-tasking easier."

> "The (PDEs) ability to understand the fundamentals of both disciplines...allowing me to approach a design or engineering problem from both sides."

> "We are far better at taking designs through to completion without compromise, than Industrial Designers."

7.7.4 A comparison of stated skills with graduate attributes required in NPD

In Chapter 1, key graduate attributes were identified by industry, engineering regulatory organisations and leading academics as critical for product design roles. Earlier in this section, the unprompted answers to the survey's open-ended question comparing PDE to ID and ME, revealed that there areas where the PDE alumni had found (based on industry experience) that they had distinct (or higher level) skills and knowledge than industrial designers and mechanical engineers.

These key skills differentiators have been mapped against the graduate attributes required for roles in NPD in Figure 7.9. The areas in green represent areas where the PDEs believe they have a skills advantage over mechanical engineers, whilst the blue represents areas of skills or knowledge advantage over industrial designers.

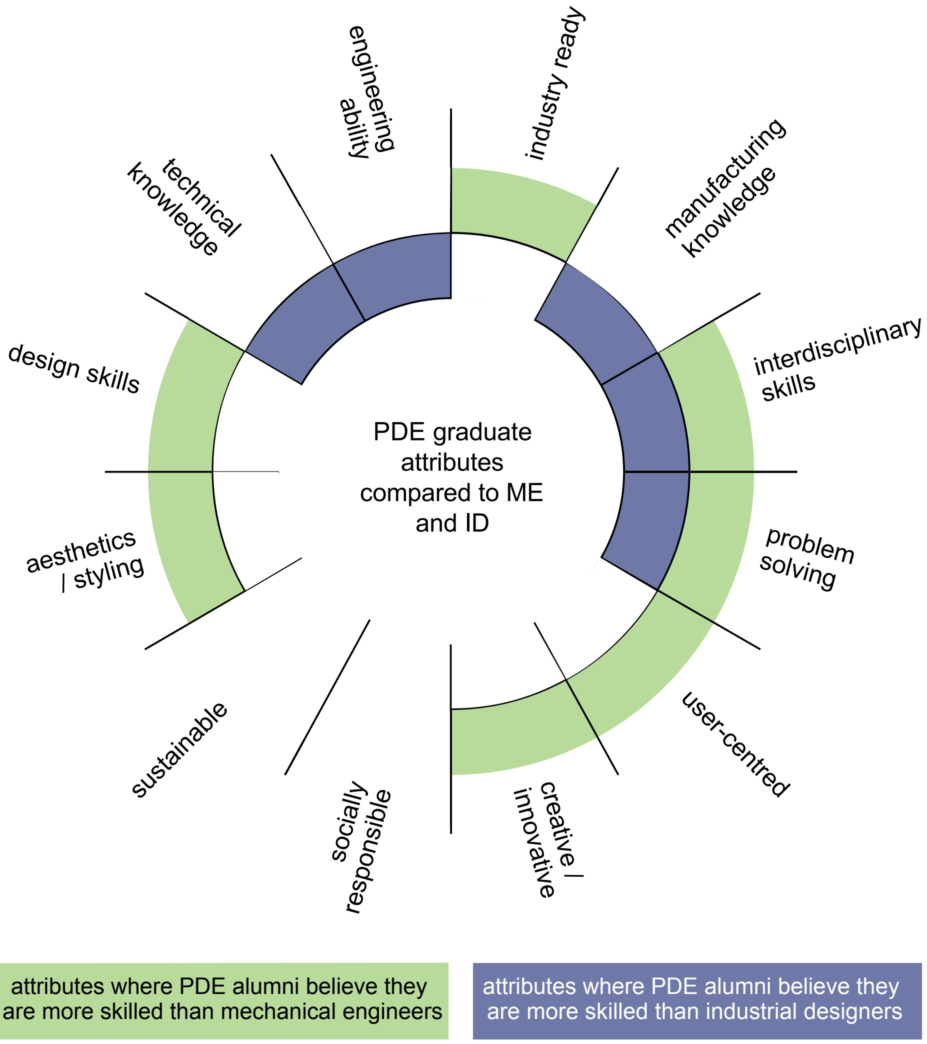


Figure 7.9: PDE attributes compared to industrial designers and mechanical engineers, mapped against NPD graduate attributes (data source: PDE Curriculum Benchmarking Survey 2010)

It is immediately apparent that the PDE alumni, without prompting, have identified ten of the twelve key graduate attributes identified in Chapter One as essential for roles in new product development. This is an important validation of the PDE curriculum, as it is evident that the skills of PDE identified by the alumni, match the graduate attributes required by industry.

Sustainability and socially responsible design were not mentioned in the PDE's self comparison against industrial design and mechanical engineering, however these issues are addressed in the agree/disagree questions that follow in the next section.

7.8 Skills and attributes comparison with other engineers

At this point in the survey, the PDE alumni were asked to complete a series of quick agree/disagree questions which compared specific skills or attribute against other engineering disciplines in their workplace.

These seven multiple choice questions dealt with: creativity, design skills and sketching ability, user needs, sustainability, social responsibility, front end design, and inter-discipline liaison, aiming to clarify the standing of PDE against other engineering disciplines in new product development. The questions were structured with five selection options for responses ranging from 'strongly disagree through to strongly agree. These questions (which were also asked during the interviews of PDE employers, refer Chapter 8), aimed to identify key skills differentiators and provide quantitative data. Accordingly, opportunities were created for comparative evaluation between the self-analysis of the PDE alumni, and the professional judgment of their employers, in regard to key attributes.

7.8.1 Creativity

In response to the first question, "As a PDE, I am more creative than other engineers," 87 percent of the surveyed Swinburne Product Design Engineering alumni either agreed or strongly agreed, with 10 percent taking a neutral position and only 3 percent disagreeing. (refer Figure 7.10)

This was an extremely positive response from the majority of graduates, which reinforces the curriculum intent (to foster creativity through open-ended design projects) and echoed industry feedback in regard to key graduate attributes and new engineering roles for PDE in new product development.

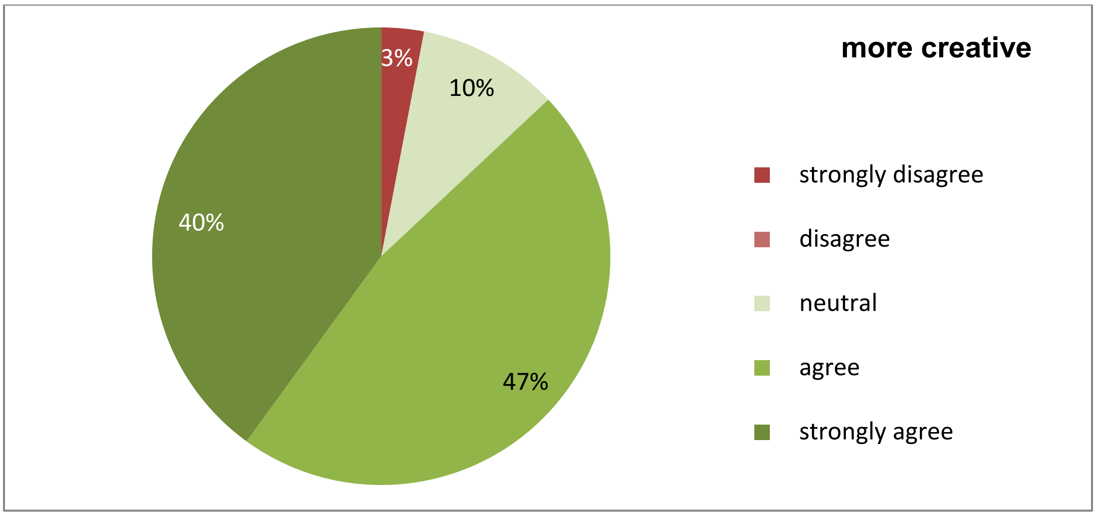


Figure 7.10: PDE Alumni opinion regarding their creativity.
(data source: PDE Curriculum Benchmarking Survey 2010)

7.8.2 The value of design skills

In response to the question "My design skills (especially sketching ability) enable me to develop concepts and design solutions more effectively than other engineers," 69 percent of the surveyed Product Design Engineering alumni either agreed or strongly agreed, with 22 percent taking a neutral position (refer Figure 7.11).

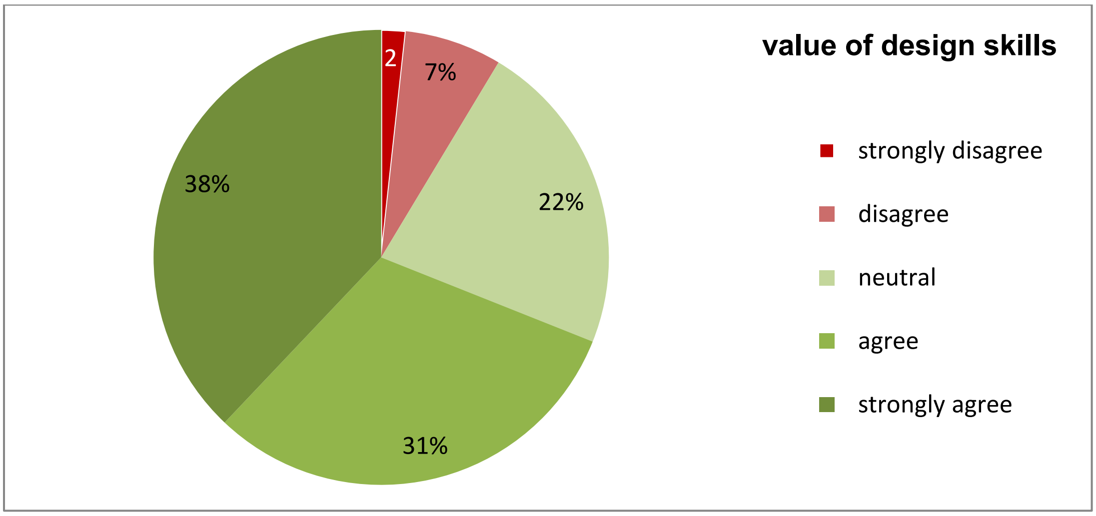


Figure 7.11: PDE Alumni opinion regarding the value of their design skills and sketching ability
(data source: PDE Curriculum Benchmarking Survey 2010)

A closer analysis of responses revealed that those who assumed a neutral position or disagreed had graduated prior to the 2006 course reaccreditation, where the curriculum was re-focussed to place greater emphasis on comparable design skills to Industrial Design. Whilst the initial course structure aimed to develop *design-informed* engineers, the current PDE curriculum states its intention to develop multidisciplinary professionals with interchangeable skills, suitable for employment in new product development as either a product designer or engineer. Accordingly later graduates expressed greater confidence in their design abilities.

7.8.3 Aware of user needs

In response to the question "I am more aware of (and responsive to) user needs than other engineers," the response was overwhelming agreement. The data reveals that 86 percent of the surveyed alumni either agreed or strongly agreed; with 4 percent disagreeing and 10 percent taking a neutral position (refer Figure 7.12).

The data reinforces the user-centred design philosophy of the PDE curriculum. This specific training is unusual in engineering education, but a determining characteristic of Product Design Engineering curricula, noted by alumni in this survey and by industry employers in interviews (see Section 8.12).

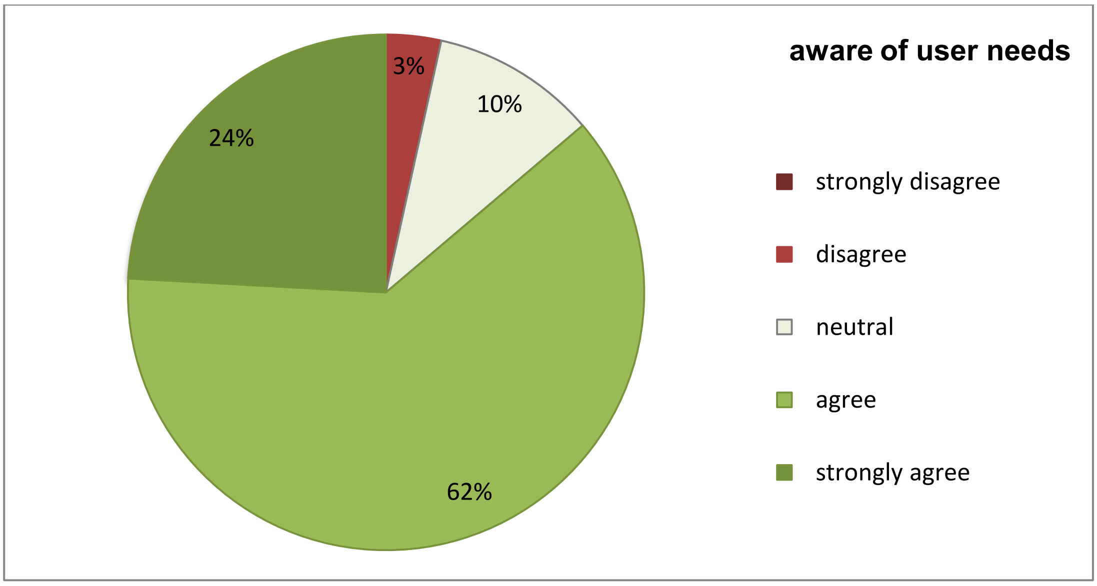


Figure 7.12: PDE Alumni opinion regarding their awareness and responsiveness to user needs (data source: PDE Curriculum Benchmarking Survey 2010)

7.8.4 Sustainable

In response to the survey question "I am more sustainable in my professional work than other engineers," the response whilst still positive was less straightforward with only 55 percent of alumni respondees answering 'agree' or 'strongly agree', and 31 percent taking a neutral position, as shown in Figure 7.13.

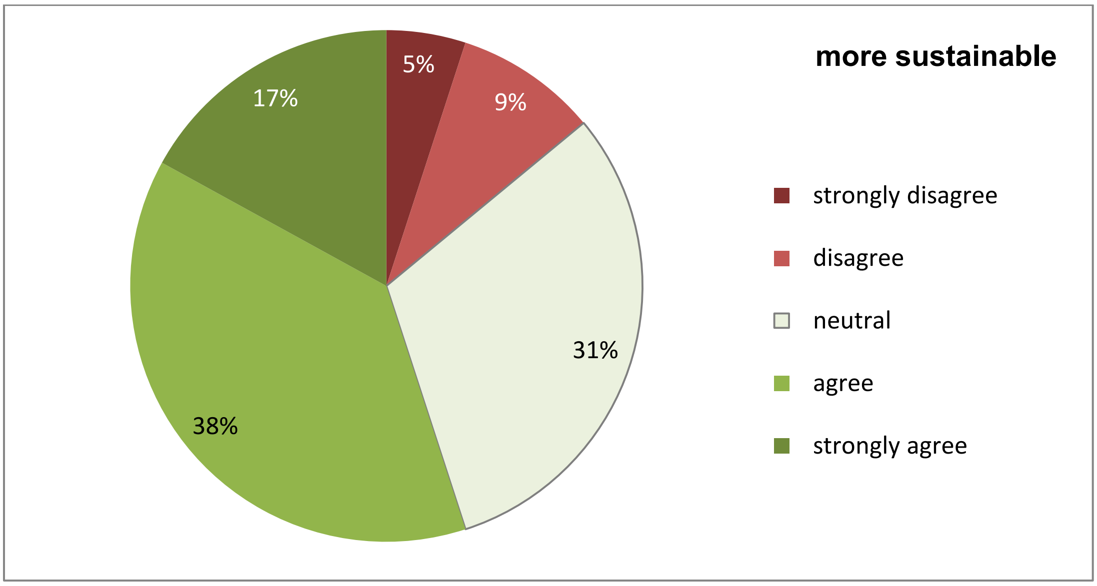


Figure 7.13: PDE Alumni opinion regarding levels of sustainability in professional work (data source: PDE Curriculum Benchmarking Survey 2010)

Whilst these results are disappointing considering the current emphasis on sustainable design in the PDE curricula, as discussed earlier (in Section 7.5) half of the surveyed alumni graduated prior to course reaccreditation in 2006, and therefore did not receive specific training in sustainable design nor socially responsible design.

7.8.5 Social responsibility

This question asked alumni if they considered themselves "more socially responsible than other engineers." Socially responsible was clarified in the question as being "more aware of the impact of my professional activities, ethical in approach, more considerate of cultural and humanitarian issues, or engaged in socially responsible design (SRD) to improve human well-being and livelihood."

As in Section 7.8.4, results reflect the 'before' and 'after' course reaccreditation make-up of the surveyed alumni. Ten respondees viewed the question as 'not applicable' and declined to answer. Therefore the results seen in Figure 7.14 have been adjusted to represent percentages of those alumni who *did* answer the question, rather than the entire respondee group. Despite the adjustment, positive response figures are still low with only 46 percent of answers being either 'agree' or 'strongly agree'.

However a close examination of the responses indicated that the positive responses came overwhelmingly for alumni who had graduated since the course reaccreditation in 2006, and who benefited from specific training in socially responsible design, with the earliest graduates most likely to have refrained from answering or responded negatively.

It must also be expected that many graduates are engaged in commercial product development and may not have the opportunity to drive these agendas in their organisations at this early stage of their careers. However educators must take a long-term view; we are teaching life-long skills and it is probably too early in the PDE paradigm for the impact of all teachings to be evident in the workplace.

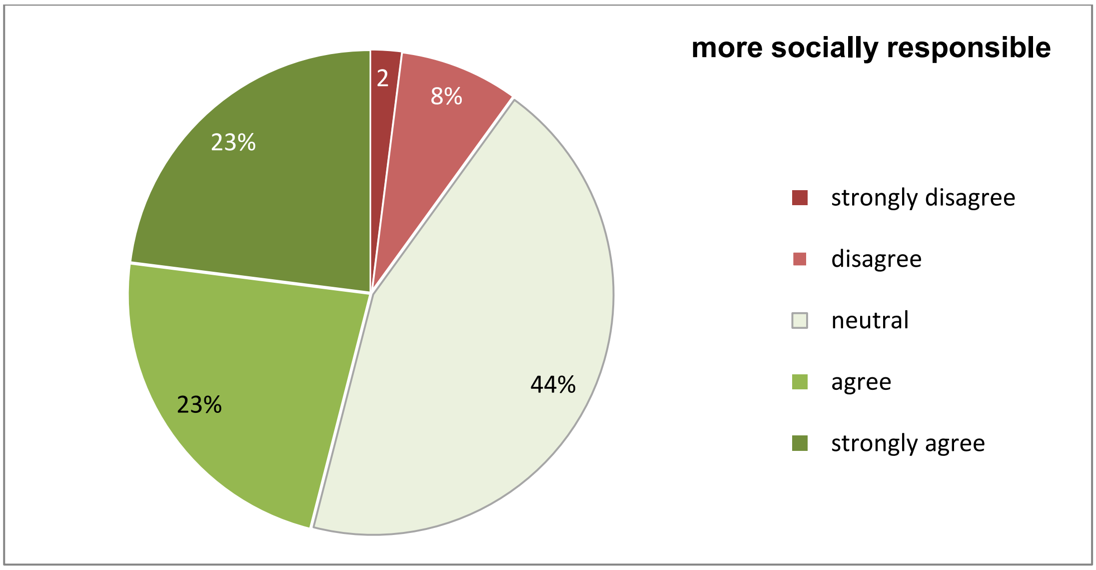


Figure 7.14: PDE Alumni opinion regarding their level of social responsibility (data source: PDE Curriculum Benchmarking Survey 2010)

7.8.6 Engaged in front-end stages of product development

In response to the question "I am more involved in the early (front end) stages of product development (e.g. conceptual design, product planning and ideation) than other engineers," the response was much more positive. As evident in the data (presented in Figure 7.15), 76 percent of the surveyed Swinburne Product Design Engineering alumni either agreed or strongly agreed, with only 12 percent taking a neutral position and 12 percent disagreeing.

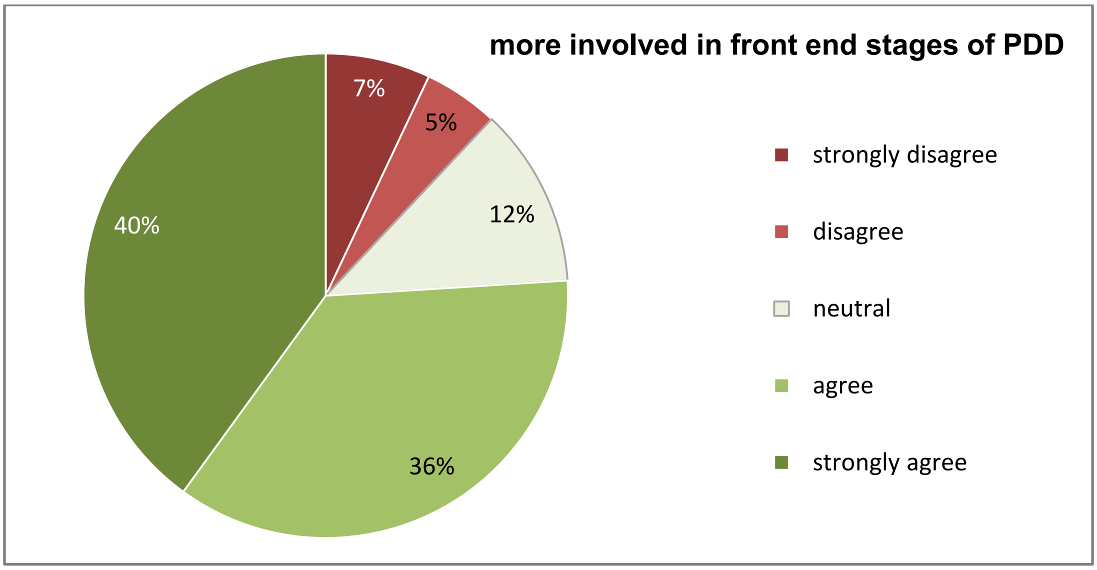


Figure 7.15: PDE Alumni opinion involvement in front-end stages of product development (data source: PDE Curriculum Benchmarking Survey 2010)

This data is highly encouraging as it indicates that the Product Design Engineering curriculum is achieving its goal in terms of adequately preparing engineers for roles in all areas of new product development. To achieve such high rates of engineering involvement in front-end activity, especially ideation, indicates that the focus on design and sketching throughout the PDE curriculum is impacting on professional roles and responsibilities in NPD industries.

Whilst this trend has been apparent through anecdotal evidence, this data represents proof of a change in team structures within product design and manufacturing industries, in response to the emergence of Product Design Engineering as a new engineering discipline.

7.8.7 Multidisciplinary skills for effective liaison

Multidisciplinary ability has been identified as a key graduate attribute for new product development. The question "My disciplinary knowledge and skills enables me to effectively liaise with different professions" aimed to discover whether the nature of Product Design Engineers enabled them to be 'multilingual' in design and engineering languages; enabling effective cross-discipline communication. Employer feedback had suggested that graduates were moving quickly into liaison roles within their organisations prompted by their fluency in the skills from both engineering and design, and ability to understand the needs of both disciplines in product design and development.

The response by the surveyed Swinburne PDE alumni supported the hypothesis with 88 percent of respondees either agreeing or strongly agreeing, and only one respondee disagreeing as shown in Figure 7.16.

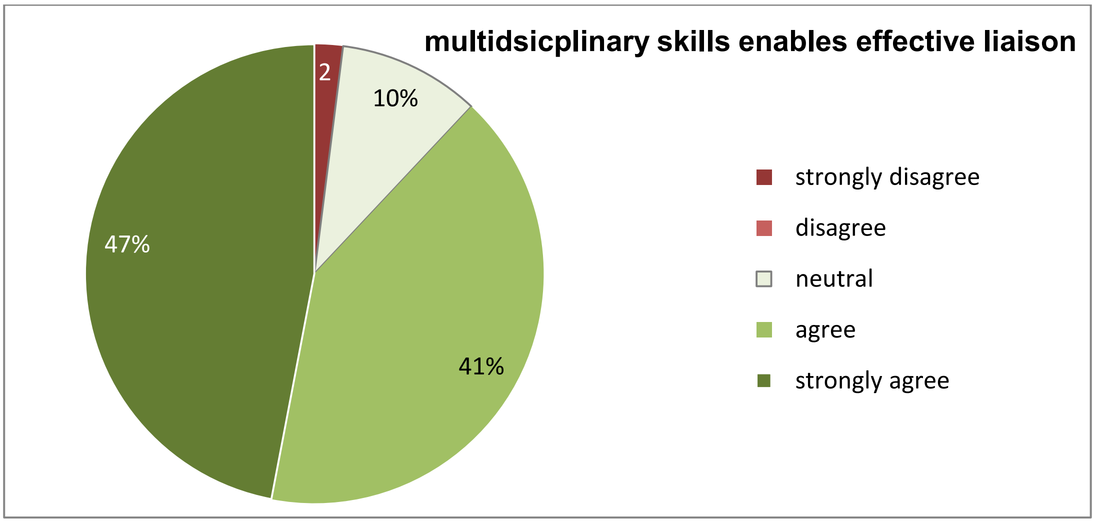


Figure 7.16: PDE Alumni multidisciplinary skills enable effective liaison with other professions (data source: PDE Curriculum Benchmarking Survey 2010)

This data reveals one of the major benefits of multidisciplinary education; the development of professionals who operate with a broad capacity of skill and understanding. Whilst it is essential to have narrowly focussed expertise in specialist roles, from an organisational perspective, staff that transcend traditional barriers are beneficial for clear lines of communication and effective inter-discipline collaboration. These are some of the key roles for Product Design Engineering.

7.9 Additional skills (not currently in the PDE curriculum)

Whilst the Swinburne PDE curriculum is broad with specialist training in both design and engineering, there is always room for improvement in a course that aims to be industry relevant. The PDE alumni were asked to nominate additional learning areas for inclusion in the curriculum based on the requirements of their profession.

Whilst most expressed satisfaction with the level of industry-preparedness they had as graduates, many had suggestions for curriculum extension to provide additional knowledge and skills sets. This additional knowledge responded directly to expanded roles for Product Design Engineers and poses a dilemma for curriculum development.

It is apparent that Product Design Engineers are considered to be flexible and adaptive design engineers with fluency in many distinct areas. This 'interdisciplinarity' places far greater demands and expectations on the PDE graduates than for single discipline graduates. The survey reveals a need for additional skills including:

- marketing and market research,
- business and people management,
- client liaison, and
- commercial decision making processes.

This suggests an extension of employer expectations and potentially rapid career progression. There appears to be an expectation that the PDEs 'can do anything and everything.' As the Swinburne Product Design Engineering course is only four years in duration, compared with five years for the 'undergraduate' Masters courses in Europe, there is little capacity to broaden the scope of the course further to include these additional skills, without negatively impacting on the core skills of design and engineering. However the introduction of the (four subject) elective minor does provide the opportunity for additional study areas particularly in regard to developing business and marketing acumen.

Industry expects a high level of specialist skills from Product Design Engineering, and accordingly, generalist knowledge must be supported by high level skills.

Nonetheless there were many suggestions that are feasible and can be implemented into the PDE curricula as they compliment or expand existing learning, including:

- industry mentoring, more industry engagement, more site tours,
- more manufacturing and product implementation knowledge, (including tooling, assembly, packaging, costing, global realisation issues, systems engineering, design proofing),
- a greater emphasis production documentation (inc. tolerancing),
- greater electronics knowledge, and
- more thorough integration of engineering theory into the design subjects.

These suggestions extend existing teaching practice and are easily accommodated within the ongoing refinement of curriculum delivery. There were also suggestions that relate directly to graduate experiences, which may be more difficult to accommodate within the existing course structure, including:

- ergonomics, not just anthropometrics but psychology and cognition,
- cost sensitive design / design to a budget,
- more project planning / management including product implementation, financial and commercial considerations and product feasibility,
- client liaison / people management,
- management and business knowledge, and
- market research and analysis.

It is in attempting to incorporate these additional skills that the weakness of multidisciplinary education becomes apparent. There is never sufficient time to develop deep understanding and a high level of expertise in all areas. Critical decisions need to be made with regard to strategic direction and core skill sets otherwise the curriculum can quickly become diluted. Whilst it would be advantageous to graduate engineers with high levels of competency in design, engineering, *and* business management and marketing, one must be realistic as to employer expectations of graduate competencies, and the timeframe available in the undergraduate program. However, a proposed Master of Product Design Engineering qualification (which is under development) may accommodate skills extension into business and marketing.

7.10 Awareness of the PDE discipline

As a relatively new engineering discipline, Product Design Engineering is vulnerable to a lack of awareness or understanding across industry, schools and the wider community. This was revealed by PDE program coordinators in the PDE Curriculum Benchmarking Survey (refer Chapter 2, section 2.11) and is evident in the Swinburne PDE alumni survey responses.

Whilst that survey revealed that the NPD industries have a relatively high level of understanding and respect for the PDE curricula, awareness is considerably lower in other industries and graduates often have to act as ambassadors for the PDE discipline in the pursuit of new employment opportunities.

The Alumni Survey asked the Swinburne PDE alumni whether they had encountered a lack of awareness, or understanding of the course and graduate attributes, and if this has impeded on their career progression.

7.10.1 Impact on alumni

As is shown in Figure 7.17, thirty of the fifty-four respondees indicated that they had faced a lack of understanding of the PDE discipline that necessitated explanation with eleven (20 percent) indicating that this has hindered their career, mostly in seeking employment, rather than in career advancement.

Most alumni felt that this lack of awareness or understanding was not a major impediment with many referring to it as a difficulty during the employment-seeking stage, but easily overcome with explanation at interview.

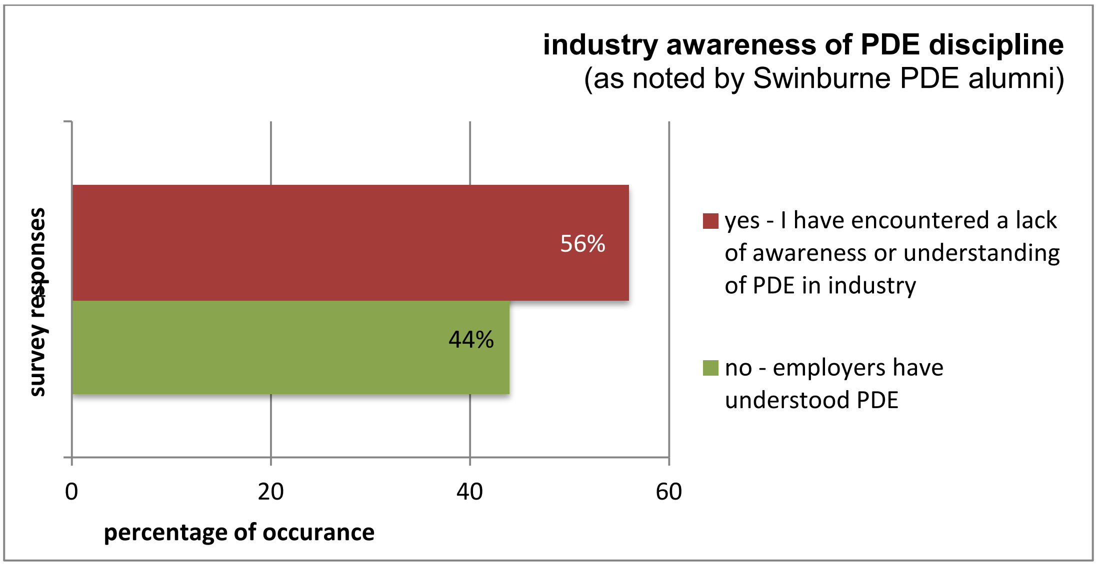


Figure 7.17: Industry awareness of PDE discipline as noted by Swinburne PDE alumni (data source: PDE Curriculum Benchmarking Survey 2010)

However, alumni commented that although employers tended to be aware of the PDE discipline, it was often difficult to get through the initial recruitment agency selection process as PDE awareness is typically much lower in the wider community.

> "Recruitment agencies are generally poor at understanding what kinds of jobs fall within your skill set."

> "Recruitment agencies need to know more about us. They are the gateway."

> "In job agencies I don't think my skill set was really understood, however when applying directly to the employer, (rather than through an agency) I have had no problems."

The alumni also noted that it is rare for large organisations or recruitment agencies to specifically advertise for Product Design Engineers. PDE graduates typically apply for advertised positions such as product designer, product engineer or even mechanical engineer and then reposition themselves at interview.

> "Advertised PDE graduate positions are rare."

7.10.2 Lack of professional recognition

This situation is not helped by Engineers Australia, the engineering industry regulator responsible for engineering education course accreditation. PDE alumni complain that the application forms for graduate or professional membership do not allow them to be recognised as Product Design Engineers, forcing them to select the closest profession (which is mechanical engineering). This denies PDE graduates the opportunity to be registered as a distinct engineering profession.

Although Engineers Australia accredit the Swinburne Product Design Engineering course and recognise PDE as an engineering specialisation in its Accreditation Board 'Fields of Specialisation' G07 document (Engineers Australia 2008), its Career Development Centre (in the 'Professional Development' section of their website), overlooks Product Design Engineering when it lists the 'main' disciplines of engineering under the heading "What is engineering?" (Engineers Australia 2012).

This lack of public recognition by the regulatory body, whilst understandable for a course offered by only one institution, is detrimental to the establishment of a new engineering discipline and the gaining of public recognition. Product Design Engineering commenced as an undergraduate engineering degree course at Swinburne in 1997, following international examples a decade earlier. It has been through several course reaccreditation processes since then, and has placed more than 200 graduates into related industries. Although the companies who employ PDE graduates acknowledge the contribution that PDE has made to their workplace, the regulatory body in Australia does not acknowledge Product Design Engineering as a distinct engineering discipline, or promote it as career option for school leavers.

This has a significant impact on community and employer awareness, resulting in low enrolment figures and the ongoing need for PDE graduates to prove their abilities and earn the respect of their engineering colleagues. Alumni explained that:

> "Both in applying for, and securing jobs, I have had to explain and convince employers of a PDE graduate's professional ability. As a PDE in a large organisation, I find I constantly have to qualify my skills."

> "Most employers don't really know how to treat your qualification"

In addition, the Australian Department of Immigration and Citizenship's Skilled Occupation List (Australian Government 2011) lists thirty engineering occupations that have been declared as skilled professions by the relevant assessing authority, Engineers Australia. Product Design Engineering is not included. This has had direct impact on the eligibility of Swinburne's international PDE graduates who seek permanent residency in Australia after graduation, and has made the Swinburne program less desirable for international students.

7.11 Conclusion

The data gained for the 2010 survey of Swinburne PDE alumni highlights some interesting characteristics of this relatively new engineering discipline.

Despite a lack of professional recognition of the PDE as a distinct engineering discipline, the majority of graduates find work promptly either as Product Design Engineers or in related fields, with most securing employment within three months of course completion. The Swinburne Product Design Engineers secure employment in a wide range of industries with the 54 survey respondees employed in 14 different industries, although most are employed in three main industry sectors:

- manufacturing,
- product design and development and the
- automotive industry.

Although industry roles and responsibilities are diverse, the most common professional roles for PDE alumni are in design and development, engineering design project management, design for manufacture and conceptual design. These results indicate that not only are PDEs working in a cross-discipline capacity, they are also occupying typical roles for industrial design.

The alumni identified several key aspects of the PDE curriculum that was beneficial in their employment with multidisciplinary ability (88%) considered the most important, followed by creative problem solving ability (86%), industry-based learning (internships) (69%), design skills (60%) and project-based learning (59%).

When examining their skills against those of mechanical engineers or industrial designers, they highlighted their:

- multidisciplinary skills,
- blend of creativity and technical ability,
- understanding of all aspects of product design from marketing to manufacture
- inter-disciplinary communication ability and,
- the broader (holistic) scope of their approach to product development.

In comparison with mechanical engineers, they perceive themselves as more creative and user-centred, with highly developed design skills a good understanding of marketing and customer needs and well prepared for industry.

In comparison with industrial designers, they believe they have greater technical ability and manufacturing knowledge, project management skills, engineering analytical ability and a broader scope of practice.

The responses of the PDE alumni to the survey reveal that (in their opinion) they possess all of the graduate attributes identified as essential for roles in new product development, and indicate a graduate cohort who:

- have appropriate graduate attributes that match the needs of their workplaces,
- have benefited from a multidisciplinary curriculum, and
- are creative, design engineers.

The validity of these alumni claims will be ratified in the employer interviews (in following Chapter 8: *Industry Relevance*) in which employers of PDE graduates were also asked to compare the skills and attributes of Product Design Engineers with mechanical engineers and industrial designers.

It appears from the findings of this research that there is a discrepancy between what is occurring in education, and awareness and acceptance in the wider community. Professional recognition and promotion within Australia, and its immediate region is a necessity for this new engineering discipline. There is a need for greater accountability on behalf of educators and the regulator, Engineers Australia, to develop the discipline, and ensure graduates are not disadvantaged.

Chapter 8: Industry relevance

8.1 Overview

This chapter analyses and interprets the qualitative and quantitative data gained through interviewing the industry employers of Swinburne Product Design Engineering graduates. The semi-structured interview process used mostly open-ended, and unprompted, questions which aimed to gain an understanding of the success of the PDE curriculum from an industry perspective, in terms of:

- PDE graduate strengths and weaknesses,
- skills comparison with industrial designers and mechanical engineers,
- PDE contribution to new product development,
- NPD workplace benefits of engineers with creativity and design skills,
- graduate career progression,
- female Product Design Engineers,
- graduate workplace preparedness, and
- industry relevance of the course.

Interview subjects were also asked a series of ‘agree/disagree’ questions that were identical to those asked of the alumni in the 2010 Swinburne PDE Alumni survey (refer Chapter 7, Section 7.8), to corroborate the validity of graduate statements in that survey.

These interviews sought evidence of the appropriateness of the Product Design Engineering curriculum as a training vehicle for engineering roles in new product development.

8.2 Introduction

The Product Design Engineering program aims to develop creative, user-centred and multidisciplinary design engineers for roles in new product development. The curriculum is tailored to meet the expectations of that industry, the requirements of the engineering regulatory (and course accreditation) organisation Engineers Australia, and to address critical societal and professional agendas as identified by luminary engineering academics.

Feedback from industry employers is critical to the validation of the discipline as an appropriate preparation for roles in new product development. The interviews with employers of Swinburne PDE alumni were necessary to:

- examine the relevance of the curriculum,
- gain an informed industry assessment of the PDE graduates strengths and weaknesses, and
- measure the contribution of this new engineering discipline to NPD industries.

The industry employers interviewed, represented a range of industry sectors, and consisted of both engineers and designers.

8.3 The data collection process

This research was conducted in accordance with the requirements of the Swinburne University Human Research Ethics committee, who granted approval on 21 April 2010 for 'Interviews of Employers of Product Design Engineering Graduates' (Ethics Clearance No. SUHREC Project 2010/042).

The semi-structured interviews (refer List of Interview Questions in Appendix 3), aimed to understand the role of PDE graduates in the product design and development workplace and validate the relevance of the PDE curricula.

Interviews were conducted under the condition of anonymity. Care was taken to ensure that references to specific companies or individuals were avoided. Interviews were recorded then transcribed with a coding system that identified only the profession of the interview subject and their type of industry. Whilst it may be possible for an individual to be identified through the original transcripts, the thesis includes only selected quotations in a manner that maintains the subjects' confidentiality. Quotations were selected for inclusion where they directly reflected on the key strengths or weakness of graduates, with care taken to ensure that they were representative of the majority of responses.

A semi-structured interview process was used to provide a degree of flexibility. Whilst most questions were less structured to allow wide ranging discussion, agree/disagree questions were also included to generate quantitative data that could be directly compared to the data from the alumni survey in Chapter 7. The qualitative data generated by the discussions was categorized and grouped into areas of commonality and measured as percentage of occurrence.

Interviews were conducted in December 2010 with fourteen industry representatives. Eleven subjects were interviewed in person at their workplace in Melbourne, two were interviewed by phone (one of whom is based in Sydney) and another responded to the interview questions by email from his current employment location in China. Interviews were digitally recorded then transcribed verbatim. For confidentiality reasons, names and company information are not included with the data.

Interviewees were approached to participate in this research based on their:

- employment and supervision of multiple PDE graduates
- employment of both industrial designers and mechanical engineers, and
- engagement in product design and development activities

Interviewees were therefore in a position to provide an informed commentary on their observations of the skills and contribution of Product Design Engineers within their workplace, and to provide a comparative evaluation of Product Design Engineering with industrial designers and mechanical engineers.

8.4 Selection of interview subjects

The interviewees were selected from a wide range of new product development industries, as follows:

- electronic product development and technology commercialisation,
- start-up bio-medical engineering for point of care (specialists in electro-mechanical, microfluidics, electronic) (2),
- industrial design/ product design consultancies (4),
- product development, bio-medical instrumentation /contract manufacture,
- automotive interior design (including seat manufacture),
- design for public domain (city council),
- child safety seat/restraint manufacture,
- manufacture of mechanical systems (including construction power tools),
- biomedical product development, and
- automotive vehicle manufacture (2).

This can be summarised as three companies engaged in bio-medical engineering/ production of medical diagnostic equipment, four product design consultancies, two automotive manufacturers, three light industry manufacturers, an electronics development company and a town planning office as shown in Figure 8.1.

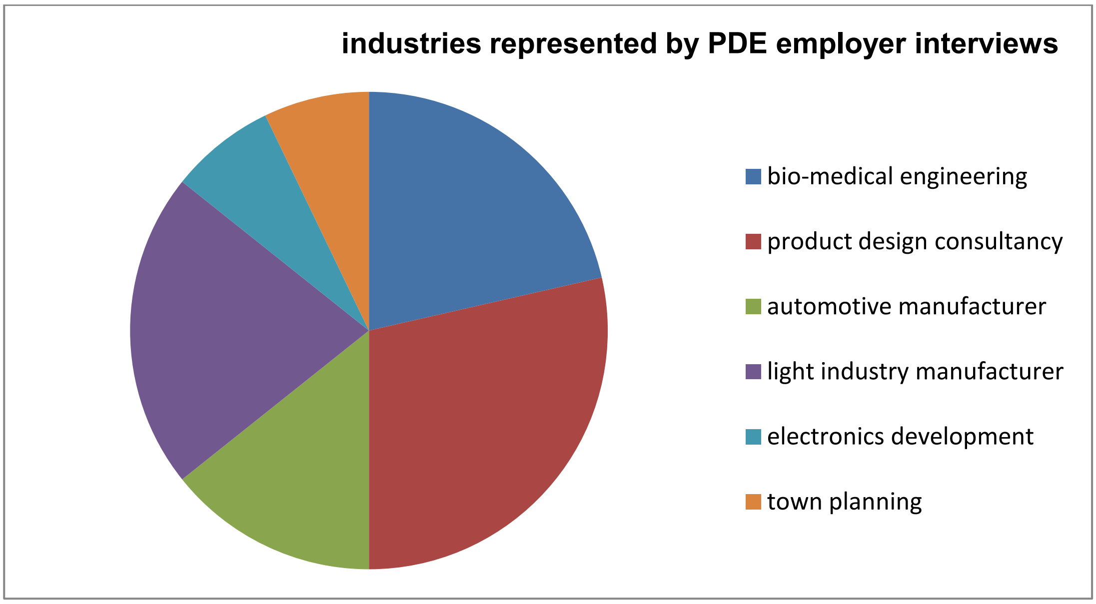


Figure 8.1: industries represented by PDE employer interviews
(data source: Interviews of PDE employers 2010)

Whilst this range of industries is representative of the diversity of employment possibilities for Product Design Engineers, there are additional industries (not represented here) where Swinburne PDE graduates have gained employment including heavy industry (rail (tram/train) manufacture, truck manufacture, air-conditioning/building infrastructure, engineering consulting, defence (military) equipment, mining industry and retail point of sale and branding. However the selected interview subjects represent a good cross section of employer industries and professional activities. All interviewees had multiple exposures to Product Design Engineering, enabling an informed and experienced evaluation.

Importantly for the impartiality of the interviews, the professional disciplines of interview subjects are typical of product design and development, with six industrial designers, six mechanical engineers, and two other engineers being interviewed.

8.5 Strengths of Swinburne PDE graduates

The interviews commenced with the employers of PDE graduates being asked to consider the strengths and weaknesses of the Product Design Engineering graduates, as observed within their organisation. The strengths of the PDEs were examined initially, and this open-ended question resulted in a diversity of responses, but several key strengths emerged throughout all responses. These have been summarised below in Figure 8.2.

The strengths most commonly mentioned by the PDE employers were:

- well prepared for industry – effective immediately,
- drawing skills,
- understanding of the new product development process,
- manufacturing knowledge, and
- creativity.

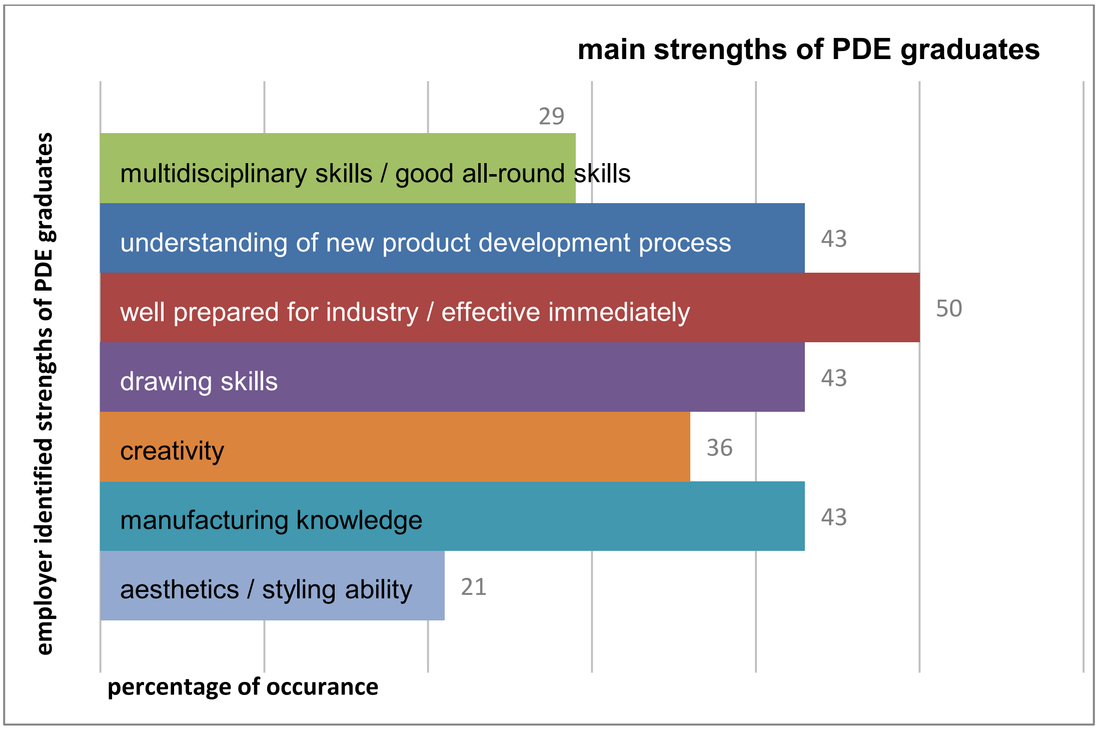


Figure 8.2: employer identified strengths of PDE graduates
(data source: Interviews of PDE employers 2010)

These responses validate the self-analysis by the Swinburne PDE alumni (Chapter 7), who also highlighted creativity, multidisciplinary approach, design skills, manufacturing knowledge and industry readiness as key attributes of the discipline.

Whilst many responses included a level of assumption, (e.g. when someone is described as having all round skills in new product development it can be assumed that this includes drawing skills), the results here include only those attributes that were specifically mentioned.

8.5.1 Well prepared for industry

The PDE curricula specifically focuses on the development of 'industry-ready' graduates through project-based learning (including industry-led projects), industry internships, and direct industry engagement in curriculum delivery as revealed by the 2010 Curriculum Benchmarking Survey (see Chapter 2, Section 2.10.7).

Almost half of the interviewed PDE employers explicitly commented that the Swinburne PDE graduates were well prepared for industry roles with the potential to make an immediate contribution to the NPD workplace. Industry-readiness was identified in Chapter 1 as a key graduate attribute for engineers in new product development. For employers to specifically highlight it as a PDE graduate strength, provides evidence of the relevance of the PDE program.

The following unprompted answers suggest that Product Design Engineering has achieved one of its key objectives; the industry preparedness of its graduates:

> "The great thing about PDE is that they come 'ready to go', that the biggest thing for us."
> [employer no. 8: design for the public domain – industrial designer]

> "The multi-disciplinary aspect of the PDE course prepares graduates well for our industry." [employer no.2: bio-medical engineering - engineer]

> "I think an element of PDE is that they can consider both ends of the spectrum, they come out better prepared."
> [employer no.3: design consultancy - – industrial designer]

> "We can make money from a PDE graduate straight away – (they have) a higher level of skills and understanding."
> [employer no. 4: design consultancy– industrial designer]

> "They have the skills that are genuinely appealing to a business such as this one. That is their key strength. They are productive and profitable quickly." [employer no. 5: design consultancy– industrial designer]

> "The breadth of their knowledge (for a graduate) – they have great ability to come in and hit the ground running – that is very important for us."
> [employer no. 11: manufacturer of construction power tools – mechanical engineer]

> "All round ability ... (they) can get started in a role and be effective very quickly." [employer no. 14: automotive manufacturer – mechanical engineer]

> "As far as graduates go, they are very useful, immediately useful and that's a great result." [employer no.1: electronic product development – engineer]

8.5.2 Understanding of the new product development process

The Product Design Engineering program, differs from mechanical engineering in that it is specifically targeted at the new product development (NPD) environment. Whilst students receive broad instruction in mechanical engineering, the design projects explicitly focus on product design with students given opportunities to develop skills and knowledge across the entire product design and development process.

The following statements by PDE employers indicate that the PDE curriculum has been successful in educating engineers who are highly employable in that professional environment, with a broad understanding of all processes from ideation to manufacture.

> "So it (PDE) is focussed on what we actually need, its strength is that it is holistic in its view of product development...and there is more of a sense that what goes on in the full process of product development is instilled in the students, which is just fantastic."
>
> [employer no.1: electronic product development- engineer]

> (The PDEs have a) fairly good understanding, well rounded in both the engineering and more aesthetic industrial design space, so probably a more commercial outcome. They are certainly more aware of what it takes to get a product to a commercial ready stage."
>
> [employer no. 4: design consultancy – industrial designer]

> "They (PDEs) came out into industry with a lot more knowledge."
>
> [employer no. 5: design consultancy – industrial designer]

> "They have a good understanding of product design and development processes from ideation through to transfer to manufacture."
>
> [employer no. 6: design consultancy/bio-medical products – mechanical engineer]

> "The PDEs obviously have their heads on straight in terms of what they think works, both from an aesthetic point of view , a functional point of view and considering the practical aspects of manufacturing and durability. They have a good understanding of the typical processes of product design and development."
>
> [employer no. 7: design/manufacture of automotive interiors – mechanical engineer]

> "(PDEs have) very broad knowledge of the design business, a very open mind, good understanding of the engineering philosophies but can look at a problem from a design viewpoint...they have good process knowledge."
>
> [employer no. 13: automotive manufacturer – mechanical engineer]

> "I think they are miles ahead of most graduate engineers, because engineering degrees don't teach design. They are better at applying their engineering theory to a problem, I think the PDE course is more practically disposed and a lot more aligned with immediate vocational practice." [employer no.3: design consultancy - industrial designer]

8.5.3 Drawing skills

The emphasis on design skills, especially drawing, has been discussed at length earlier in this research in Chapter 4. The PDE Curriculum Benchmarking Survey discovered that 94% of the surveyed PDE programs (refer Chapter 2, Section 2.10.4) required their graduates to be fluent and proficient at drawing. Drawing is considered to be an essential skill for PDE graduates and the curriculum aims to develop aptitude in ideation, technical and explanatory sketching. Course leaders commented that drawing was "absolutely essential," "a key part of the design thinking process" and "a fundamental link to creativity."

The employers of the Swinburne PDE alumni have benefited from these key skills, seeing the sketching ability of the PDEs as a skills differentiator and key strength, as can be seen from the following employer observations:

> "One of the key benefits they have is hand drawing communication skills, which are really important. Drawing is a key discriminator, when you need to communicate something you need to do it better than with words and you don't want to be hampered by the need to go to CAD. I think that is the key (with the PDEs) that's one of their key strengths. Hand drawing is what makes them different from everyone else."
>
> [employer no.3: design consultancy - industrial designer]

> "PDEs are enthusiastic, good at drawing, good at concept development."
>
> [employer no. 12: bio-medical product development - industrial designer]

"Their abilities in this area (design ideation) have been a real benefit. Ideas need to be fleshed out quickly, this is a vital stage of the design process and sketching is critical to this."

[employer no. 5: design consultancy - industrial designer]

"PDE go from conceptual to documentation to managing the prototype to evolving and testing to implementation. From beginning to end including the presentation drawings, so that is the best part (of the PDEs). They can do all of that stuff."

[employer no. 8: design for the public domain - industrial designer]

"Presentation and drawing skills – they are able to present material that is very descriptive, the capability to portray / communicate their ideas is very important and there have been no exceptions to that with the PDEs. They are able to sell an idea. They are very much in tune with the creative designers."

[employer no.13: automotive manufacture- mechanical engineer]

"(Their) key strengths are creativity and ability to sketch."

[employer no. 6: design consultancy/bio-medical products - mechanical engineer]

8.5.4 Manufacturing knowledge

The project-based learning curriculum of PDE emphasises 'design for manufacture' and affords students the opportunity to apply theoretical knowledge to product outcomes. This is particularly important in the area of plastic part design, a highly specialised field usually the domain of professional industrial designers, and typically not covered in mechanical engineering curricula.

The Product Design Engineering students are well versed in the opportunities and constraints imposed by differing materials and manufacturing processes and are expected to be competent at resolution for production, before course completion.

This was reinforced by the PDE employers who identified manufacturing knowledge as another key PDE graduate strength, as evident from the following statements:

"The PDEs have a better understanding of materials and plastics when compared to the ID grads."

[employer no. 4: design consultancy – industrial designer]

"I think they have a pretty good knowledge, much better than industrial designers in terms of manufacturing processes....they are better prepared from a materials and (processes) understanding point of view."

[employer no.3: design consultancy – industrial designer]

"(They have a) good understanding of manufacturing processes."

[employer no. 6: design consultancy/bio-medical products – mechanical engineer]

"They understand the practical aspects of manufacturing"

[employer no. 7: design/manufacture of automotive interiors – mechanical engineer]

"They have good process knowledge."

[employer no. 13: automotive manufacturer – mechanical engineer]

"They seem to have plastics totally under their belt, compared to the Mech. Engineers who say 'oh yeah, we covered that in one day.' PDE really do understand the principles of (plastics) moulding, (they) embrace the process, (and are) aware of the technical requirements."

[employer no. 10: design consultancy – industrial designer]

8.5.5 Creativity

Another major PDE strength identified by employers was creativity, also identified by global PDE program leaders and alumni as a key characteristic of the discipline. Creativity was identified by program coordinators as a key student competency in the curriculum survey (refer Figure 3.13) and an area of the curriculum that had received industry commendation (refer Chapter 2, Section 2.12.1).

This global employer preference for creativity was supported by Australian employers of PDE graduates who highly value creativity as a key strength as evident from the following statements:

"We look for creativity. You get to see this more easily expressed with the PDEs. They can express creativity without reliance on a CAD system and that is one of their key abilities."

[employer no.3: design consultancy - industrial designer]

"(The PDEs strengths are) the design, the creative aspect of it, being able to come up with a good engineering solution that is a bit more innovative and applies some lateral thinking."

[employer no. 7: design/manufacture of automotive interiors – mechanical engineer]

"They (PDE) meet all the criteria - creativity and innovation."

[employer no.9: manufacturer automotive safety seats/ restraints – mechanical engineer]

"Creativity – there are massive benefits for us in employing a creative design engineer."

[employer no. 12: bio-medical product development - industrial designer]

8.5.6 Summary – strengths

It is apparent from the employer interview process that Swinburne PDE has been successful in achieving its main curriculum objectives; to develop creative engineers who are well prepared for employment in the product design and development industry. The strengths identified by industry employers matches the stated course objectives and intent for graduate attributes. That is to develop creative and technical design engineers with strong design skills, for new product development roles.

It was not unexpected that the course's graduates should receive such positive affirmations as students benefit from the program's close relationships with industry and strong industry engagement in the teaching program. The suitability of the alumni for employment in PDD was already well known through employer feedback and the high employment uptake of Swinburne PDE graduates. Less anticipated were the weaknesses identified by the PDE employers during the interviews.

8.6 Weaknesses

The employers of the Swinburne PDE alumni were then asked to identify any weaknesses they had observed in the Product Design Engineering disciplines. As shown in Figure 8.3, half of the interviewed employers were extremely positive about the PDE program and could not identify any weaknesses.

However, some weaknesses were identified by employers that may have implications for the PDE curricula and/or the delivery of the teaching program. As could be expected with a multidisciplinary curriculum, employers identified three critical areas that impact on PDE graduates professional performance as follows:

- a lack of depth in engineering,
- an identity crisis (designer or engineer), and
- frustration at the lack of multidisciplinary opportunities.

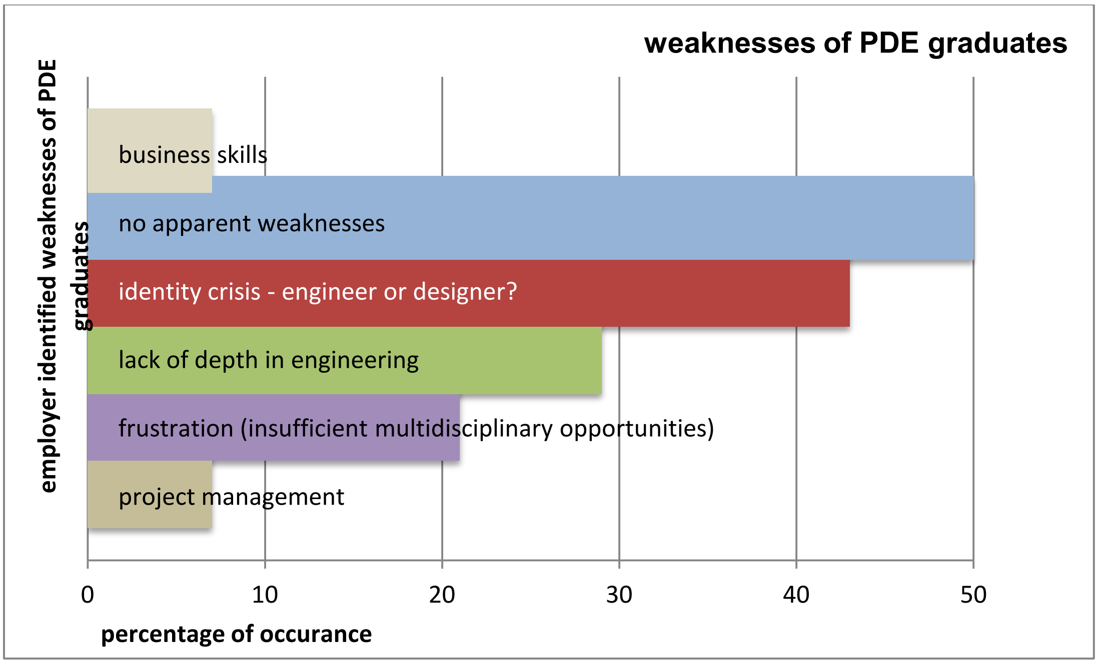


Figure 8.3: employer identified weaknesses of PDE graduates
(data source: Interviews of PDE employers 2010)

8.6.1 A lack of engineering depth

29 percent of interviewed employers of Swinburne PDE graduates identified a lack of engineering rigour and technical depth amongst the PDE alumni they had employed. Whilst this was only four responses (out of fourteen) it was concerning that some employers thought that the Product Design Engineers were less capable when faced with purely engineering tasks, especially those involving advanced calculations, with employers stating:

> "If you need extreme precision (e.g. on bio-medical), we wouldn't use the PDE, we would use the specialist mathematical calculations based engineering skill-set." [employer no. 6: design consultancy/bio-medical products – mechanical engineer]

> "If we have the need for pure mechanical engineering, we will outsource it. The PDEs are not generally solid enough in the Mech. Eng. side, they can assist us from a team work side, but we send the specialist engineering work out, rather than do it in-house."
> [employer no. 4: design consultancy – industrial designer]

It was the product design consultancies that identified this specific weakness, not the manufacturers, who likely have specialist engineers in their employ. In small product development teams where there is insufficient work to justify the employment of a mechanical engineer, the PDEs are typically expected to do all of the engineering tasks and this is where their lack of depth has been apparent.

The PDE curriculum offers a total of 32 units (over four years) of which twelve are design units and four are electives (minor stream). This means that the PDE undertake sixteen engineering theory units compared to the mechanical engineering course (which requires students to complete 28 engineering theory units).

As discussed in Case Study 1: *Examination of the Swinburne PDE Curriculum,* although Product Design Engineering students complete most of the engineering foundation units, they attempt only two (of four) mathematics subjects. They also lose technical depth (compared to mechanical engineering students) in Machine Design, Solid Mechanics, Thermodynamics, and Fluid Dynamics, but gain the mechanical engineering electives of Design for Manufacture and Human Factors.

None of the missing mechanical engineering content is particularly necessary for engineers engaged in product design, however the lack of depth in some areas of engineering can lead to uncertainty when faced with complex mathematical calculations and engineering analysis.

Employers observed that the perceived lack of engineering rigour may be due to the PDEs choosing to 'occupy' one headspace (design) over the other (engineering). In the case of PDEs who have chosen a career path in industrial design consultancies, it is apparent that these graduates are more design focussed. Unlike a 'T-shaped' educational model where the foundations of engineering are established before design training commences, the PDE model develops both design and engineering skills simultaneously. Resultantly, some of the PDEs have been observed to think more like designers (where anything is possible) without the analytical questioning, focus and restraint that is typical (and expected) of engineers.

As is evident from the employer observations below, it is perceived that the multidisciplinary educational model of PDE, whilst adding new multidisciplinary skills, has lost some level of engineering 'rigour'.

> "Their strength is their weakness – in that they don't seem to have the same rigour and questioning as a pure Mech. Eng. does. Engineers generally say 'prove to me that it works, I need to see validation of it' and at times you need a voice in the development process to say 'hang on, this whole concept is relying on this – lets prove it first'. And I haven't seen that mindset as much in the PDE guys. They tend to choose one head space over the other and I probably get the ones who are more inclined to design. Whilst I want them to be creative, I also want them to sit back and 'go hang on a minute'. They don't question and check as much as the MEs." [employer no. 10: design consultancy – industrial designer]

> "Expediency is not always the solution. You need thoroughness, engineering rigour and I don't always see that with the PDEs. The rigour hasn't been there. I haven't had the same level of problems with young mechanical engineers. The PDEs are probably less focused on the engineering because of all their other skills. Sometimes the PDEs are out of their depth with depth of engineering understanding."
>
> [employer no.3: design consultancy – industrial designer]

Although four employees observed this trend, not all identified it as a specific weakness. Two of the interviewed employers indicated that they would use specialist engineers in specific areas and that they did not expect the Product Design Engineers to be competent in all areas of engineering science; their multidisciplinary skills outweighing any weakness in engineering theory.

> "This is not a weakness, but other engineering courses focus more on physics, force analysis, energy chains, fluidics and PDE has a basic knowledge, but not to the depth of other engineering grads. Because of their multi-disciplinary education, maybe their focus is not purely on the science, they don't have the same level of engineering rigour."
>
> [employer no. 6: design consultancy/bio-medical products – mechanical engineer]

8.6.2 An identity crisis

It is not unexpected in multidisciplinary educational curricula to find instances of identity crisis. The PDE lecturing staff have been aware since the course inception that individual students and graduates would favour one discipline (design or engineering) over the other.

Regardless of which direction graduates prefer, they are still beneficiaries of a broad skills and knowledge base, coupled with the ability to approach problems with consideration for both disciplines. The intention of the PDE course is to provide opportunities for students to gain proficiency in the skills of both professions, and to set a base competency level that ensures professional capability in either design or engineering.

So it was surprising to find almost half (43 percent) of the surveyed employers had found that the PDE graduates can suffer from an identity crisis and have confused expectations regarding their role as either designer or engineer.

> "I have seen some (PDEs) struggle to understand whether they are a designer or an engineer." [employer no.6: design consultancy/bio-medical – mechanical engineer]

> "Some evidence of confused expectations re their role in organisation.
> The PDE guys have struggled a bit because their expectations are quite

high...maybe the PDEs come out thinking they have already got a place, but in fact they need to find or define their place."

[employer no. 5: design consultancy – industrial designer]

"Focus conflict which is the absolute outcome of the paradigm of trying to get right brain and left brain working together in one person – a potential identity crisis."

[employer no. 11: manufacturer of construction power tools – mechanical engineer]

"I have some issues with PDEs having uncertainty about whether they define themselves as designers or engineers – sometimes they are undecided in this. Some of them are frustrated designers."

[employer no. 13: automotive manufacturer – mechanical engineer]

Despite observing that some PDE graduates struggle with their own professional identity, none of the employers indicated that this had significant impact in the workplace. There was no mention of the 'jack of all trades, master of none' label that often accompanies those with multiple skills. However some employers felt that lack of a 'specialisation works against the PDEs; that some workplaces are looking for advanced skill sets in specific areas.

"You need to be good at something; you won't always be doing everything, so a bit of specialisation would be ideal to bring a specific skill to the business. Being a generalist can work against you."

[employer no. 5: design consultancy – industrial designer]

It appears that the biggest issue for employers to manage is a tendency for frustration amongst the PDEs. Trained for both disciplines, many find themselves 'pigeon-holed' into one specific area at the expense of utilisation of their other skills.

Interestingly, some of the PDE alumni surveyed raised also raised this issue, but attributed the 'identity crisis' as originating from the workplace (rather than the PDE) with graduates (in the survey of PDE alumni) stating:

"Some companies like to define your skill set as one or the other (designer or engineer) from early on and it can be difficult to explain to them that you are capable in both areas." and,

> “I've certainly had to explain what PDE is time and time again. Particularly to older engineers and management who believe you are either a 'nuts and bolts' mech. eng or a 'coloured marker waving' designer, but not both.”

This sentiment is supported by interviewed employers with one stating that,

> “One of the challenges for industry is recognising / understanding that identity crisis, and making sure that the role reflects the needs of the graduate, because ultimately you want to match graduates and roles. I’m not sure that industry yet understands what these multi-disciplinary people are, nor how to keep them fully occupied – that has been one of our challenges – these guys are so broad.”
>
> [employer no. 11: manufacturer of construction power tools – mechanical engineer]

This issue is understandable with a program that develops graduates with such diverse and unprecedented skill sets. Industry will take time to fully appreciate the potential of the Product Design Engineering discipline, especially as individual graduates have their own skills and knowledge discipline emphasis.

Employment ‘pigeon-holing’ will continue until employers specifically recruit for Product Design Engineering positions, as some in Melbourne now do. At present PDE graduates are often required to apply for non-multidisciplinary roles as product engineers, design engineers, product designers etc; assigning themselves to a singular (not cross-discipline) employment role, limiting future options for a more varied workplace contribution and later causing frustration.

8.6.3 Professional frustration

The issue of the professional frustration experienced by Product Design Engineers appears to be two-fold. The ‘identity crisis’ (as discussed in Section 8.6.2), whilst frustrating from an employment categorisation point of view, is compounded by roles and responsibilities assignation in the workplace.

Many of the PDEs find themselves in ‘engineering only’ positions and are frustrated that their creativity and design skills are under-utilised. This is particularly evident in larger manufacturing organisations, such as the automotive industry, where roles are selectively prescribed and there is little opportunity for employees to move from engineering to design tasks, particularly aesthetic styling. The following observations from large manufacturing employers support this:

> "I know that sometimes they get a bit frustrated with the fact that the automotive industry is very conservative, there isn't a lot of opportunity to really explore their ideas. So that can set them up for a little bit of disappointment. A lot of the work is fairly prescriptive and I think that stifles their creative urge to some extent. The students coming through the PDE course do have that side to them, they want to be a bit more creative and in this conservative environment they can feel a bit stifled."
>
> [employer no. 7: design/manufacture of automotive interiors – mechanical engineer]

> "Some of them are frustrated designers, in automotive they won't ever be creative designers in the automotive industry, because it is very competitive. The ones that think they can draw, by comparison to automotive designers, their sketching is immature."
>
> [employer no. 13: automotive manufacturer – mechanical engineer]

> "I have seen some level of frustration where they want to be doing more than just functional design – they want to be styling at the same time."
>
> [employer no. 11: manufacturer of construction power tools – mechanical engineer]

However, this issue does not appear to be of concern in the smaller organisations, such as design consultancies, where the PDEs have more opportunities to express their multidisciplinary capacity, and their design skills are more valued and utilised.

> "The PDEs have the skills we need. They are the ideal starting block for a consulting role, and I wouldn't put on a graduate that didn't have that cross-over skill." [employer no. 5: design consultancy – industrial designer]

> "So we need someone to cover all the bases – the PDEs suit us well."
>
> [employer no. 8: design for the public domain – industrial designer]

> "The PDEs are a good fit in a small engineering team - as here we need to be quite broad. We don't have the luxury of a car design environment where roles are compartmentalised and narrow...that doesn't work here."
>
> [employer no. 10: design consultancy – industrial designer]

8.6.4 Summary - weaknesses

The employer interviews identified three main areas of weakness in the Swinburne PDE graduates: lack of depth in engineering, an identity crisis (designer or engineer), and professional frustration.

Of these, the identified weakness in depth of engineering science is expected as the PDE curriculum dictates this with a reduction in depth of engineering content in mathematics, fluid dynamics, thermo dynamics, machine dynamics and solid mechanics, to allow for the inclusion of design curricula.
In this regard, the balance between engineering and design curricula must be the subject of ongoing review as multidisciplinary curricula is always exposed to vulnerability in perceived depth of knowledge and skill sets.

However, it is widely known and somewhat expected that multidisciplinary professions will lack depth of specialist knowledge, but this does not appear to have been detrimental to the Product Design Engineers. Employers appear to value their multidisciplinary abilities, over any lack of depth of engineering science.

> "Perhaps they do not have the depth in some of the technical disciplines but their strengths outweigh any potential weaknesses."
>
> [employer no. 14: automotive manufacturer – mechanical engineer]

8.7 Comparison with Industrial Design and Mechanical Engineering

> "I think that it is a fantastic course, which is why I keep hiring your graduates over any other industrial design or mechanical (engineering) course... I haven't employed an industrial designer since you started the (PDE) course. It's a quantum leap over anything that I have seen before."
>
> [employer no.1: electronic product development – mechanical engineer]

PDE employers were asked "Why would you employ a PDE rather than a Mechanical Engineer or Industrial Designer?" As PDE graduates possess most of the skills from both those professions, and are being employed instead of MEs and IDs, it was pertinent to understand what characteristics result in PDEs being the preferred profession in product design and development environments.

8.7.1 The relative skills of PDE

The interviewed employers of Swinburne PDE graduates identified a range of distinguishing and preferred characteristics that resulted in the employment of a PDE rather than a mechanical engineer or industrial designer. The key characteristics are shown below in Figure 8.4.

It should be noted that the commonality of language evident in some responses (e.g 'better fit' and 'skill-set') did not result from prompting by the researcher, as these were open-ended questions.

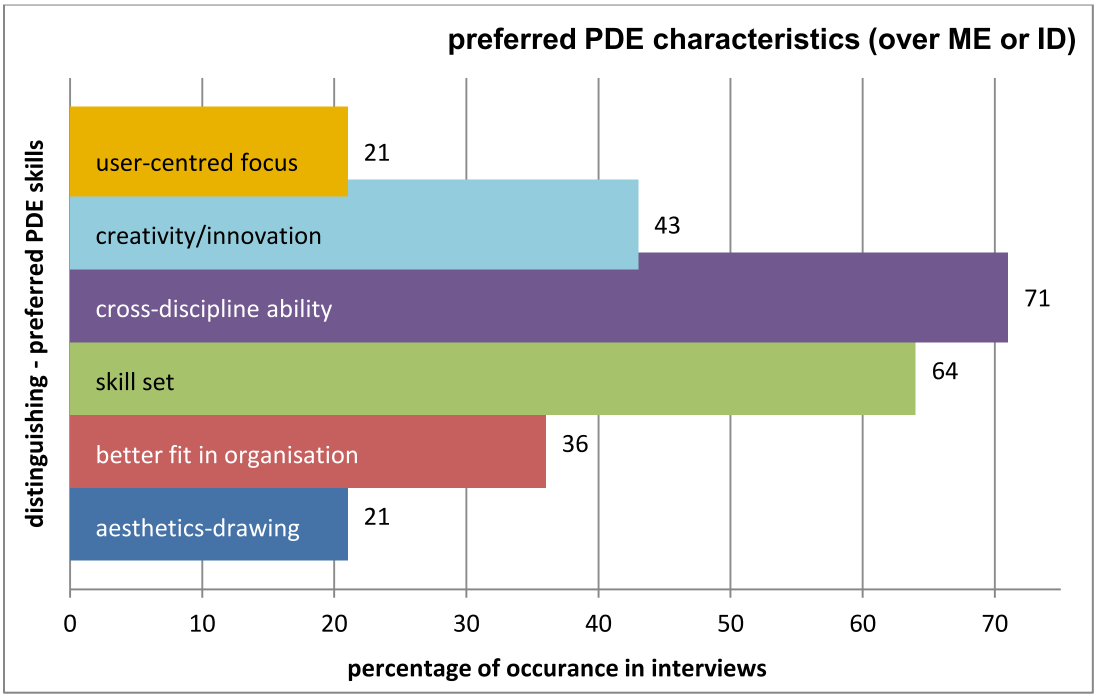


Figure 8.4: distinguishing–preferred characteristics of PDE graduates
(data source: Interviews of PDE employers 2010)

It is apparent that the cross-disciplinary nature of the PDE graduates is highly valued (with 71 percent of subjects specifically mentioning it), followed closely by skill-set (64 percent), then creativity/ innovation (43%) and 'better fit in organisation' (36%). Also explicitly referred to was the PDE's user-centred focus and aesthetics /drawing ability (both at 21%).

Employers also referred to the "organisational benefits from the PDEs:

- cross-discipline liaison" ("they can translate between the different crews"),
- preparation, ("they don't need their hand held like an industrial designer"),
- understanding ("the PDEs have the thinking process right, they understand design...they are pushing upwards"), and
- their "effective leadership".

8.7.2 PDE compared to Mechanical Engineers

Although the question asked employers to compare the relative merits of both industrial designers and mechanical engineers in regard to employability, most answers focussed on comparisons between PDE and mechanical engineers. This was most likely due to PDE's recognition as 'engineers', allowing easier comparison.

Employers identified four main areas of differentiation between Product Design Engineers and mechanical engineers:

- cross-disciplinary ability,
- a broad skill set,
- creativity/innovation and,
- a better organisational fit.

(a) Cross-disciplinarity

The multidisciplinary nature of Product Design Engineering appears to be highly regarded. All of the manufacturing industry employers commented on the lack of design ability demonstrated by mechanical engineering graduates, and welcomed the PDEs ability to balance the requirements and constraints of the engineering and design environments and apply engineering knowledge to design problems.

> "We need someone who has a very good balance between engineering and philosophy of design. The PDE course gives me someone who is sympathetic to design and I don't believe the ME course gives the students the chance to understand what design is about."
>
> [employer no. 13: automotive manufacturer – mechanical engineer]

"The PDEs, by virtue of that left brain/right brain mix are inherently better. I think the right brain helps them apply their left brain better. The PDEs don't just look at the *stated* problem, they look more broadly. MEs can't always translate their engineering knowledge to a problem."

[employer no. 11: manufacturer of construction power tools – mechanical engineer]

"Certainly the PDEs are more likely to generate innovative solutions, the really hardcore Mech. Eng. guys tend to focus purely on the principle engineering aspects of a design problem. The PDEs are a good blend of the two. You have the aesthetics, function and form being combined, and the understanding that it should look good, as well as function. There is a tendency for MEs to complicate everything, to come up with over-elaborate design solutions, but to forget how it is supposed to look in context to how the product is supposed to function, so you end up getting layers of covering up the ugliness underneath."

[employer no. 7: design/manufacture of automotive interiors – mechanical engineer]

(b) Skill set

The broad skill set of the PDE graduates was widely acknowledged with employers from all industries identifying the PDE's broad skill set as a preferable characteristic in terms of employability. As is evident from the following comments, the PDEs' diversity of skills appear to be more highly regarded than the more focussed skills of the mechanical engineers.

"PDEs have a broader skill set and can adapt to different roles more quickly. They also can be more effective leaders in a design engineer type role." [employer no. 14: automotive manufacturer – mechanical engineer]

"What we are trying to do is make the connection between their role as an engineer, but working in a design community. It is a cross-over of those traditional skill sets."

[employer no. 13: automotive manufacturer – mechanical engineer]

"We can get this (design) from a PDE, but we can't get any design from mechanical engineers. They don't have the finesse and the ability to look at something and critically review the aesthetics, the safety, and the usability." [employer no. 8: design for the public domain – industrial designer]

> "In the mechanical design and development group the PDEs have a very good skill-set in terms of the cross-over between industrial design and engineering."
>
> [employer no. 6: design consultancy/bio-medical – mechanical engineer]

> "We try to employ people who can be with the project from start to finish, and on that basis we try to get employ candidates that have a full width of skills."
>
> [employer no. 12: bio-medical product development – industrial designer]

(c) Creativity / innovation

Creativity has been identified in Chapter One as a key graduate attribute for engineers involved in new product development, and was revealed by the Curriculum Benchmarking Survey (refer Chapter 2) as one of the key student competencies for all global PDE courses.

The Swinburne PDE graduates are considered creative by their employers, echoing the international findings, and validating the relevance of the curriculum.

> "The other thing we look for is creativity... you see this more easily expressed with PDE." [employer no.3: design consultancy – industrial designer]

> "The PDEs are more human-centred and creative than many of our engineers." [employer no. 6: design consultancy/bio-medical – mechanical engineer]

> "When I employ a product engineer, I'm looking for someone with innovation and creativity. So the PDEs suit us – they have all the skills. Many engineers tend to design products that are uncommercial; too complex, too costly and un-manufacturable."
>
> [employer no. 9: manufacture of child safety seats and restraints – mechanical engineer]

(d) Better fit in organisation

Many of the employers of Swinburne PDE graduates stated that the PDEs were a 'better fit' in their organisation. These responses were not restricted to any specific industry sector, with large manufacturers, and small new product development companies identifying the value of Product Design Engineering to their business.

> "For us and what we do, which is very product based, the PDE graduate fits that very well. PDE is a better fit."
>
> [employer no.1: electronic product development – mechanical engineer]

> "The PDEs are more considerate of user-centred design aspects. Our products need to be comfortable, convenient and safe, so how you interact with it, and the look and feel of the product, are critical."
>
> [employer no. 7: design/manufacture of automotive interiors – mechanical engineer]

> "We have had a lot of PDEs as interns and we have continued with them due to confidence in their ability and their awareness of the design process. MEs typically are not as good at articulating ideas."
>
> [employer no. 10: design consultancy – industrial designer]

> "MEs have had limited success here, the PDEs are a better fit for my business. They have a good understanding of design, but they are very much mechanically minded as well."
>
> [employer no. 13: automotive manufacturer –mechanical engineer]

8.7.3 PDE compared to Industrial Design

Not all of the interviewees were in a position to compare Product Design Engineering and industrial design graduates. Typically, those responses were from established employers of industrial designers, product design consultancies, rather than manufacturing environments. The manufacturers, who employ a large number of engineers, understandably focussed their responses on comparing PDEs with MEs.

Comparisons between Product Design Engineers and industrial designers fell into two broad categories; technical ability and creativity. Interviewed employers typically identified the industrial design graduates as conceptual but lacking the ability or discipline to resolve technical and manufacturing details. This aligns with the opinions of the Swinburne PDE alumni (Chapter 8, section 8.7.3) and global coordinators of PDE programs.

> "They (PDEs) don't need their hand held like an industrial designer. I used to hate hiring them (IDs) because they didn't get it. IDs suffer from lack of technical understanding in many ways – they are not good at technical resolution."
>
> [employer no.1: electronic product development – mechanical engineer]

> "The PDEs, due to their multidisciplinary course, are a lot more focussed and resilient, whereas a lot of IDs study design as an easy option and don't necessarily have the discipline."
>
> [employer no. 10: design consultancy – industrial designer]

> "I find that the PDEs are more skilled and well-rounded in terms of abilities than ID grads." [employer no. 5: design consultancy – industrial designer]

> "There is a big difference between ID and PDE due to the engineering base. The PDEs are more tenacious on the detail whereas a lot of the IDs are purely conceptual, a specification approach rather than full resolution." [employer no. 8: design for the public domain – industrial designer]

Also evident from these interviews was the impact that PDE has on team structure in industrial design consultancies. The PDEs strength in technical resolution is confining industrial designers to the creative front-end, with the PDEs doing the bulk of the product development after client concept approval. This development work used to be the responsibility of industrial designers.

> "In the first instance, the designer is the champion, and then the PDE drives it through to resolution, detailing, documentation, and supervision of production. They can cover areas that the industrial designers can't. In the old days we used to have to do it ourselves, but now we have a better option (the PDEs)." [employer no. 10: design consultancy – industrial designer]

> "PDEs are taking jobs from IDs. That is because ID has been redefined, they have been squeezed out by the engineering growth in the middle of the NPD process, and they have been pushed into the brand, communication and user interface. IDs are primarily used for high-end visuals, surfacing, and understanding of form."
>
> [employer no.3: design consultancy – industrial designer]

8.8 Workplace contribution

The interviewed PDE employers were asked to explain the roles of PDE graduates in their organisation. The responses indicate that the PDEs are not just engaged in 'back-end' product resolution, but are assuming leadership roles, and actively managing the design project through to production. Employers described the Product Design Engineers as 'really central' and 'the engine room' whilst another referred to structuring product development teams around the PDEs (supported by specialists). As many of these comments come from industrial design consultancies, this is significant. As discussed earlier in this chapter, Product Design Engineering has had a significant impact not only on the discipline make-up of PDD teams, but also on internal new product development processes.

Due to the influence of PDE, the role of engineering in the Melbourne design consultancy environment appears to have moved from technical resolution and engineering analysis, to ownership of the project from the initial stages, through to production.

> "(They are) really central, pushing and owning the product. They are trying to keep the product together as a whole. They are really taking that role well. They are involved in the project from concept to close-out and testing. As we grow as a company, our intent is to make that group (of PDEs) bigger and stronger with a lot more going on. We will bolt the specialisation on around the PDD team."
>
> [employer no.2: bio-medical engineering - engineer]

> "The PDEs are the 'engine room', they are involved in the (early) design stages, but more as prodders and protagonists rather than the champion, but once the design is defined then it will be handed over to the PDE who will then be the project leader and the ID, who was involved in the front end, will become a support. So they almost swap roles at that point. In the first instance the designer is the champion making the calls, but with the engineers input, and then the PDE drives it through to resolution, detailing, documentation, supervision of production."
>
> [employer no. 10: design consultancy – industrial designer]

"The PDE are doing the development and the detail. The ID might set the direction and then the PDE will take over and maintain the design intent and fully develop it into commercialisation. We have three senior designers; two are ID and one PDE. As PDE is a relatively new profession, it is quite an achievement to have a senior who is a PDE."
[employer no. 4: design consultancy – industrial designer]

8.8.1 The role of PDE in small design teams

Whilst in many organisations, the PDEs responsibilities commence after the conceptual design, in smaller design teams the Product Design Engineers are making a contribution across the whole process, from concept to production.

"Conceptualisation, presentation, prototypes and implementation – the whole project" [employer no. 8: design for the public domain – industrial designer]

"The PDEs do everything a senior designer does. They will do everything in this business. Concept sketching, visualisations, renderings, right through to documentation and project management. They are very capable of stepping up to these roles, their confidence in their abilities helps." [employer no. 5: design consultancy – industrial designer]

"They do all of the PDD processes, concepts to manufacturing. They are good at designing the product for marketing, the end user, safety, manufacturing and developing technical innovation."
[employer no. 9: manufacture of child safety seats and restraints – mechanical engineer]

"Our department is very fluid, we try to employ people who can be with the project from start to finish; that way they take their inherent knowledge *with* the project and then if there are production issues, they understand the concepts, and why things were done a certain way.
[employer no. 12: bio-medical product development – mechanical engineer]

"PDEs do the concept work, styling, design for manufacture, documentation, standard operating procedures (SOPs), detail design, cost reduction, product assembly refinement and assisting in broader engineering roles. So it is vital that our PDEs have an understanding of process and passion for how things work."
[employer no. 11: construction industry power tools – mechanical engineer]

8.8.2 The role of PDE in large design teams

In the larger organisations, it appears that the PDEs assume leadership or liaison roles, performing critical cross-disciplinary roles between the specialist professions.

> "PDEs are used as the interface between the engineering centre and the design styling centre."
>
> [employer no. 13: automotive manufacturer – mechanical engineer]
>
> "They make a very strong contribution – whether as a design engineer, project leader, technical leader in the studio, (or) overall program analyst. They can move across these roles with ease."
>
> [employer no. 14: automotive manufacturer – mechanical engineer]

8.9 Workplace impact of creativity and design training

Earlier in this chapter (Section 8.7.2c) creativity and innovation was identified by many employers as a reason for employing PDE graduates in preference to a mechanical engineer. During the interview, the employers were asked "what are the benefits and implications of the PDE focus on creativity and design skills for the design and engineering teams in your organisation?"

Employer responses highlighted the PDEs role in maintaining the 'design intent' through to production without compromising the products appeal, the importance of 'joint sensibilities' in design and engineering during the PDE process, the PDEs flexible, questioning approach, and the importance of creativity in NPD. Employers also referred to the impact of the PDEs design skills and creativity in regard to team structure within their organisations.

> "The fact that we have a creative engineer means that we don't need an industrial designer. I would rather have a creative engineer than a technical industrial designer. In terms of styling the PDEs are doing it...I've never been frustrated by the lack of an ID on the staff. It is fantastic that you have pushed the design training of these engineers to a level compatible with Industrial Design."
>
> [employer no.1: electronic product development – engineer]

> "We do all the design in-house. We need an engineer with an appreciation for the creative aspects of design. I think many engineers

tend to go to a mechanical solution and then stick to it. The design component in the PDEs allows them to question and offer alternatives."

[employer no. 5: design consultancy – industrial designer]

"Design skills and creativity is a skill set that we value. We could run the whole Mechanical Development department with just a team of PDE graduates. They do provide a good skill set that bridges industrial design and mechanical detail design and they are aware of the manufacturing implications. They have a well rounded set of skills and assist in bridging disciplines."

[employer no. 6: design consultancy/bio-medical products – mechanical engineer]

"That (the PDEs creativity and design skills) is why I really like them as graduates – that's really fundamental. I really don't want the product engineering to compromise the initial vision, so having people who are strong in that all the way through (means) they won't lose the vision. Productionisation can become a filter for taking all the good stuff out. But if you give the design group excessive power you can suffer a lot of damage, because you can't have engineering sensibilities. This is why the PDEs are valuable as they are across all aspects of the process."

[employer no.2: bio-medical engineering - engineer]

"Students who are attracted to the PDE course have that creative aspect to them, so from that perspective they are a good fit. We already know where to go for good graduates if we are looking to build up that creative, innovative side to our team. The PDEs are a big benefit in this area."

[employer no. 7: design/manufacture of automotive interiors – mechanical engineer]

"It is a must. In terms of product design, I am looking for creativity and innovation and good mechanical aptitude. Without that, we don't have the product."

[employer no.9: manufacture of child safety seats and restraints – mechanical engineer]

"They (PDEs) understand the design process and they are sensitive to those product aspirational objectives that we try to inject into all of our projects. There is no resistance to it. Whereas engineers will immediately think 'why does it matter' or 'that will be hard to make' etc. You don't get that push-back from the PDEs at all."

[employer no. 10: design consultancy – industrial designer]

"We are an innovative company, we are trying to come up with new designs all the time, so there are massive benefits for us having creative people at the front end, and during the development process of any project and your curriculum focuses on that. That is fantastic."

[employer no. 12: bio-medical product development – industrial designer]

"The PDEs I've seen are more outgoing, more creative, and open to new ideas, more outward looking, whereas the MEs tend to be more introspective in their approach. I have heard people describe PDEs as a breath of fresh air in the workplace.

[employer no.3: design consultancy – industrial designer]

"It's fantastic – that is the strength of PDE.
Working with engineers with no creativity is very hard work."

[employer no. 4: design consultancy – industrial designer]

8.10 PDE career progression

It has been noted previously that the Swinburne Product Design Engineering graduates advance quickly in organisations due to their strong inter-disciplinary communication and liaison skills and understanding of the whole design and development process. This is supported by the interview responses to the question "How well do PDE graduates progress in your organisation (compared to industrial designers and mechanical engineers?"

Unfortunately, not many of the interviewed employers had employed PDEs for sufficient time to measure career progression, or the organisations were too small to have clearly defined career pathways. However, several employers did identify project management, project leadership and client/supplier liaison roles as immediate roles for advancement, and indicated that they have high and long term expectations for their PDE staff.

"PDE engineers progress to senior engineer /supervisor status perhaps more quickly than other grads. Beyond this level, it is not yet possible to say. They are very effective at delivering program solutions and effective designs and are solid coaches of the process and the people around them." [employer no. 14: automotive manufacturer – mechanical engineer]

"They have all been good at project management and liaison. The PDEs are competent in that area because they are the one group who understand." [employer no.2: bio-medical engineering - engineer]

"We haven't really reached that journey yet, but movement into project management and senior roles is quite likely. They have an ability to communicate and express their ideas, there is openness about the way they communicate and they are not focussed on the singular. They are very open at looking at the best solution rather than the 'only' solution. The communication aspect will see them into project management and we are looking at them to take on a leading role as project leaders."
[employer no. 13: automotive manufacturer – mechanical engineer]

"It's early days, we had high hopes for one (who has moved on) to move through the organisation.
[employer no. 4: design consultancy – industrial designer]

"We see them as a good long term asset that we will work hard to keep, even if it means rotating them through different offices in different countries."
[employer no. 11: manufacturer of construction power tools – mechanical engineer]

8.11 Women in engineering

The Product Design Engineering curricula has proved highly appealing to female students worldwide with global female student ratios averaging 36 percent across the fifteen surveyed PDE courses as detailed in Chapter 3 (refer Figure 3.4).

Whilst Swinburne PDE achieves only a 24 percent female student ratio, this is almost double the national (Australian) engineering average. It is significantly higher than other engineering courses at Swinburne, where Mechanical Engineering has 2 percent female students, and the Faculty of Engineering average is 10 percent across all disciplines.

Increasing female engagement in engineering is a stated aim of worldwide engineering organisations, including Engineers Australia. The Product Design

Engineering curricula clearly outperforms other areas of engineering education in its ability to recruit female students, as such it was important to measure the impact of female PDEs on typically male-dominated product design teams.

Of the fourteen interviewed employers, eight had employed at least one female PDE graduate with most employing several graduates and interns. For many of these employers, the female PDEs represented the first time they had employed female engineers. In the area of product design, where many design outcomes are market driven, it is deemed essential to have a team with good gender and cultural balance, in order to address end user and market diversity.

Many of the Swinburne PDE female graduates are employed in workplace environments that traditionally have been male dominated, and the interview responses indicate that Product Design Engineering is opening new employment opportunities for female engineering graduates.

> "PDEs are our first experience of female engineers. We have now had several female PDEs on IBL (as interns) and a graduate.
>
> [employer no. 10: design consultancy – industrial designer]

> "We have employed two female PDEs, but no other female engineers.
>
> [employer no. 4: design consultancy – industrial designer]

> "We typically employ female engineers because they have a stronger design ethic. In your course (PDE) you are appealing to the females who are doing engineering because they want to design."
>
> [employer no.2: bio-medical engineering - engineer]

The employers also indicated that these female engineers have had significant impact on their workplaces, bringing a gender balance to product development and manufacturing environments.

> "We have three female engineers, including one PDE. The women bring a better balance politically, a more measured approach. They are less competitive." [employer no. 8: design for the public domain – industrial designer]

> "It's important to have female engineers; they bring a new perspective. A totally male-dominated environment is a weakness. I can understand why PDE appeals to women. It isn't just focussing on the dry side of engineering, its human/user centred."
>
> [employer no.3: design consultancy – industrial designer]
>
> "I have employed two female PDEs. They add something fresh and help balance the work environment."
>
> [employer no.1: electronic product development – mechanical engineer]

> "We have employed three female PDEs, and have a lot of female engineers (a ratio of 6/30). One's a principle engineer, plus some senior engineers. They bring something different both in their team approach and their thought processes, perhaps a little more creative in their approach, and their communication styles are not as confrontational."
>
> [employer no. 6: design consultancy/bio-medical products – mechanical engineer]

> "We employ female PDEs and female IDs. There is a desire to change the balance within the company. They provide a different perspective and change the mindset from a typically male dominated company. We want more female engineers."
>
> [employer no. 13: automotive manufacturer – mechanical engineer]

It appears from the comments above that there is a greater need for female engineers, particularly in product design and development. In Australia, where these industries and the engineering profession have long been male-dominated, a renaissance is occurring, led in part by female Product Design Engineers who are often the first female engineer employed in these roles and workplaces.

Multidisciplinary courses such as Product Design Engineering, have proven more palatable to female students than traditional engineering curricula. The resultant increase in female graduate engineers provides new employment opportunities for employers, and a more balanced capacity for new product development.

8.12 Agree-disagree questions – comparing PDE and other engineers

Following the open-ended questions discussed above, the PDE industry employers were asked to complete a series of quick ‘agree/disagree’ questions which compared the specific skills or attributes of the Product Design Engineering graduates against other engineering disciplines in their workplace. These six multiple choice questions dealt with: creativity, design skills and sketching ability, user needs, sustainability, social responsibility and inter-discipline liaison. Expected question responses were either ‘agree/disagree’, but with the provision for a neutral response.

These questions, which were also asked during the PDE Alumni Survey (discussed in Chapter 7, Section 7.8), aimed to clarify key skills differentiators; provide quantitative data analysis and opportunities for comparative evaluation between the self-analysis of the PDE alumni and the professional judgment of their employers.

The responses (refer Figure 8.5), show overwhelming agreement in the areas of key skills such as creativity, design skills including sketching, user-centred focus and the benefits of multidisciplinary liaison. Employers took a more neutral position on sustainability and social responsibility skills and knowledge of the PDE graduates, with 50% of interview subjects assuming a neutral position. There are several possible reasons that contributed to so many of the interviewees not offering a position on the sustainability and social responsibility questions, including:

- the employees are too junior to lead social agendas within their organisation,
- some of the employers interviewed have only employed PDEs who graduated before the course reaccreditation in 2006 (which introduced these agendas in to the PDE curriculum),
- the commercial or technical nature of the organisation has not afforded opportunities for the PDEs to demonstrate their skills in these areas, or
- a lack of understanding of social design in some organisations (in several interviews, this researcher had to clarify the meaning of socially responsible design).

PDE employer interview responses to agree-disagree questions					
question	**agree**	**disagree**	**neutral**	**overall agree**	**% disagree**
PDE graduates are more creative than other engineers	13		1	93%	0
PDE design skills (especially sketching ability) enable them to develop concepts and design solutions more effectively than other engineers	13		1	93%	0
PDE graduates are more aware of user needs than other engineers	10	2	2	72%	14%
PDE graduates are more sustainable than other engineers.	7		7	50%	0
PDE graduates are more socially responsible than other engineers. (e.g. more aware of the impact of their professional activities)	5	2	7	36%	14%
The multidisciplinary knowledge and skills of PDE graduates enhances their liaison skills	13		1	93%	0

Figure 8.5: PDE employer interview responses to agree-disagree questions (data source: Interviews of 14 PDE employers 2010)

Overall (with the exception of the sustainability and social design questions) the responses were in line with expectations, and reinforced the self-analysis of the PDE alumni. The core areas of curriculum focus, and thus key graduate attributes, of creativity, design skills, user-centred design and interdisciplinary skills were all acknowledged as superior to those of other engineering disciplines.

This is not a denigration of the other engineering disciplines in product development, but rather a reinforcement of the workplace benefits of a discipline whose skills have been developed for specific roles, rather than the more generic, broader education of the mechanical engineering discipline. The specific skills of the Product Design Engineers appear to be well matched to the new product development workplace.

The ‘agree-disagree’ questions asked during the employer interviews correlated with questions in the PDE alumni survey. Table 8.6 compares the self-analysis of PDE graduates with an evaluation of the PDE discipline from their employers. For this comparison, the five-answer response range from alumni (‘strongly disagree’ through to ‘strongly agree’) has been reduced to either agree or disagree to correlate with the employer interview responses. The data is correlated from the interview responses from fourteen employers and the survey responses of fifty-eight alumni.

Comparison of PDE alumni vs. employer responses to agree-disagree questions		
question	***PDE alumni % agree***	***PDE employers % agree***
PDE graduates are more creative than other engineers	87%	93%
PDE design skills (especially sketching ability) enable them to develop concepts and design solutions more effectively than other engineers	69%	93%
PDE graduates are more aware of user needs than other engineers	86%	72%
PDE graduates are more sustainable than other engineers	55%	50%
PDE graduates are more socially responsible than other engineers. (e.g. more aware of the impact of their professional activities)	46%	36%
The multidisciplinary knowledge and skills of PDE graduates enhances their liaison skills	88%	93%

Table 8.6: Comparison of PDE alumni vs. employer responses to agree-disagree questions (data source: Interviews of PDE employers 2010 and PDE Alumni Survey 2010)

Whilst the PDE alumni scored themselves highly in most areas, this was expected of a group that had been described by industry as ‘confident in their own abilities’. However in three critical areas, it was found that employers not only agreed with the alumni’s self assessment, but in increased numbers. The PDE employer’s responses were significantly more positive than the alumni, in the questions relating to their creativity, design skills and interdisciplinary liaison skills.

Overall response ratios were similar between the employers and alumni indicating that the PDEs confidence in their skills and knowledge is echoed by industry. The responses not only correlate the earlier findings from the PDE Alumni Survey, but also support the hypothesis that the PDE curriculum achieves its aim to develop creative and human-centred multidisciplinary engineers with strong design acumen, ideally suited to the new product development environment.

8.13 Additional statements

Interview subjects were asked if they would like to add to their responses. Several took the opportunity to expand on their earlier feedback, commenting on the relevance of the course to industry and discussing the employability of the PDE graduates, as is evident below. It is evident from the feedback that employers are satisfied with the skills and approach of the Product Design Engineers, and their suitability for roles in new product development.

> "I think that you (Swinburne) run a great course – we intend to employ more of your graduates." [employer no.2: bio-medical engineering - engineer]

> "PDE is still evolving as a profession, it takes time to build experience, there have only been eight graduating years and the numbers were quite low in the early years so we are not a critical mass yet. My hope is that the PDE course is a wake-up call for other courses, and maybe they will start to specialise in areas that are relevant to the industry."
> [employer no. 4: design consultancy – industrial designer]

> "The (PDE) course is giving them the ability to contribute to industry. PDE is the closest fit for what we need."
> [employer no. 13: automotive manufacturer – mechanical engineer]

> "Maybe we get the best of the PDEs, but we have had great success with our interns and have employed all but one after graduation. The conscientiousness that we have seen in the PDEs, we don't see that in other graduates. They have a desire to be one of the best, and that is what we are looking for, not just naked ambition, but a desire to be really good at what they do." [employer no. 10: design consultancy – industrial designer]

> "The PDEs tick all the boxes, but industry needs to understand their potential better. When we do recruitment and we get the 300 applicants down to a final ten, typically two to three out of the top five are PDEs. I say to them 'Your course has benefited you greatly, it has got you here. It has made you this versatile engineering animal'."
> [employer no. 11: manufacturer of construction power tools – mechanical engineer]

8.14 Describing PDE in one word

The interviews concluded with the PDE industry employers being asked to summarise or describe the PDE discipline in a single word, in an attempt to define the 'essence' of Product Design Engineering. Figure 8.7 captures the essence of their responses in a graphical representation.

Figure 8.7: describing PDE in one word - employer interview responses
(data source: Interviews of PDE employers 2010)

Employers emphasised the Product Design Engineers' versatility (three mentions) and flexibility (two mentions), and outlined their competency, effectiveness and employability. These positive responses are evidence of NPD industry recognition of the value of the Product Design Engineering discipline.

8.15 Summary of findings

The interviews of employers of Swinburne PDE graduates provide evidence of the success of this new engineering paradigm, supporting both the objectives of global PDE program directors and reinforcing the self-analysis of the PDE alumni.

The inclusion of design curricula into the mechanical engineering program has resulted in a new discipline with the skills, knowledge and approach valued by those in product design and development.

Employers described Product Design Engineering as “a breath of fresh air in the workplace” and “a wake-up call for other courses” indicating some dissatisfaction with traditional engineering education, with regard to preparation for employment in new product development industries. The PDE graduates are seen as more practical and effective, “better at applying their engineering theory to a problem” and more creative than other engineers. They were also commended for their understanding of product design processes, manufacturing knowledge and design and drawing skills.

However employers identified some weaknesses including:

- lack of depth in engineering knowledge,
- an identity crisis (designer or engineer), and
- graduate frustration due to the lack of multidisciplinary opportunities.

As one employer identified “their strength is also their weakness.” By its nature, multidisciplinary education must reduce content in one area to allow time for the development of skills in the other discipline. With the Product Design Engineers, this has resulted in a lack of depth in mechanical engineering knowledge and possibly a lack of critical and analytical scrutiny. This is not considered a major problem as “their strengths outweigh any potential weaknesses.”

Product Design Engineers were described as the ‘engine room’ of new product development teams; more creative, adaptable, flexible and user-centred than mechanical engineers, but more ‘grounded’ and realistic than many industrial designers with a greater understanding of technical requirements.

8.16 Conclusion

Product Design Engineers appear to have made a significant contribution to the NPD workplaces in Australia, to the extent of changing team structure and professional roles and responsibilities. Some employers discussed the PDEs replacing industrial designers in their organisation, whilst others identified revised roles for industrial design. In organisations where PDEs are employed, the industrial designers have been moved exclusively to the conceptual front end, and no longer have responsibility for product development and design resolution.

The high ratio of female PDE graduates has seen changes to workplaces with some organisations employing female engineers for the first time. The appeal of PDE to young women who would not traditionally have chosen an engineering career, has created new opportunities for employee diversity, added new perspectives to NPD and balanced workplace dynamics.

Across the broad range of industries represented by the employer interviews, a common appreciation of the PDEs skills and abilities has emerged. It appears that the integration of design and engineering skills, with particular focus on preparing students for employment within product design environments has been successful.
PDE graduates are considered to be highly employable, immediately effective, versatile and innovative.

In the previous chapter, the Product Design Engineering alumni declared that compared to other engineers, they perceive themselves as more creative and user-centred, with highly relevant design skills, and a good understanding of user needs. In comparison with industrial designers, they felt they had better technical skills, plus engineering analytical ability and a broader scope of practice.

The employer interview responses validate the self-evaluation of the PDE alumni, and demonstrate the benefits of the Product Design Engineering curriculum. It appears evident that the integration of design and engineering within the PDE curriculum has developed creative and user-centred engineers, who are well prepared for roles in new product development.

Conclusion

Overview

The conclusion summarises the contribution of the research towards understanding the required graduate attributes for engineers engaged in new product development, examining the new engineering discipline of Product Design Engineering, and validating its multidisciplinary curriculum as an appropriate educational model. This is established through responses to the research objectives and an evaluation of the research findings against the research questions. Strengths and limitations and future research are also discussed, and new contributions to knowledge are highlighted.

Introduction

Cross (2000) notes the need for skills integration between design and engineering where these disciplines are engaged in new product development, whilst Fry (2006) notes a lack of synergetic approach between the two disciplines. From an educational perspective, many have called for revision in engineering curricula to enable:

- greater graduate skills in design (e.g. Dym, Agogino et al. 2005),
- creativity and innovation (e.g. Pappas 2002; Santamarina 2002; Cropley 2006, et al.), and
- sustainable and socially responsible (e.g. Beder 1997; Hammer 2007).

The US Accreditation Board for Engineering and Technology (ABET) requires graduates to have received the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context, whilst in the UK, the Engineering Council's Standards and Routes to Registration (SARTOR) requires universities to show how graduates can achieve the ability to be creative and innovative.

The literature indicates the need for a new type of multidisciplinary engineer with specific skills in design and creativity, solid engineering and technical ability and an underlying philosophy that considers the broader implications of professional activity. These attributes are not developed fully by either of the disciplines traditionally engaged in new product development, namely industrial design and mechanical engineering, but have been found by this research to define the new engineering discipline of Product Design Engineering.

Response to research objectives

The introduction to this research nominated six research objectives that aimed to investigate the training of engineers for roles in new product development (NPD) and evaluate the contribution of new engineering disciplines such as Product Design Engineering. The research findings in regard to these objectives are discussed below:

[1] Identify graduate attributes expected by engineering regulatory organisations.

This research has identified key graduate attributes for engineers engaged in new product development (see Section 1.7). This has been achieved through a review of the existing literature, an examination of the requirements of engineering regulators (such as Engineers Australia, the UK Engineering Council, and ABET) and through engagement with NPD industries.

Attributes expected from all engineering graduates include engineering aptitude and technical knowledge, design skills, creativity and innovation, sustainability and socially responsibility, manufacturing knowledge, and industry-readiness. For those engineers engaged in new product development, additional attributes are required including interdisciplinary skills, a user-centred focus, ill-defined problem solving ability, and enhanced design skills including sketching, ideation and aesthetic styling ability. These attributes have formed the basis of the enquiry into the Product Design Engineering discipline.

[2] Examine Product Design Engineering as a new engineering discipline with a distinctive skill set.

Whilst the research revealed that the inter-disciplinary requirements of new product development are unlikely to be addressed solely by either mechanical engineers or industrial designers, Product Design Engineering has emerged as a new engineering discipline with a unique and differentiating skill set, capable of producing graduates with competency in all key NPD graduate skills, attributes and knowledge areas.

PDE program coordinators, globally, together with Swinburne PDE alumni and their industry employers, have contributed significant qualitative and qualitative data that point to a new engineering discipline that specifically trains industry-ready engineers for roles in new product development (refer to Chapter 2). The PDE curriculum whilst addressing critical societal agendas (e.g. sustainability, social responsibility), develops the mandated creativity, design skills, problem solving ability and user-centred focus, within an interdisciplinary methodology.

Based on employment statistics and feedback from industry employers worldwide, it is evident that the global Product Design Engineering programs are addressing the specific needs of new product development and satisfying a skills and knowledge void left by more established curricula. In Australia, despite only one institution (Swinburne) offering Product Design Engineering, there appears to have been significant graduate uptake and strong industry support for this new discipline, with employers describing graduates as highly employable (refer to Section 8.5.1).

[3] Benchmark international PDE programs, evaluate curricula and identify this commonality of purpose as a new direction for engineering education.

Initial research (see Chapter 2) investigated international instances of Product Design Engineering, through a survey of course leaders. It revealed significant commonality of curriculum intent and delivery, and similar graduate attributes, and vocational pathways for product design engineers, regardless of the educational institution from which they graduate. The emphasis on multidisciplinary skills, creativity and design ability, aptitude in open-ended problem solving, a user-centred focus, sustainability and social responsibility, and industry preparedness were apparent across all of the surveyed programs.

It is evident that the Product Design Engineering pedagogy is a growing global trend in multidisciplinary education and an innovative engineering educational model that represents possible new directions for engineering education. All PDE programs develop highly relevant vocational skills and address the requirements of regulatory organisations for the development of creative and responsible design engineers (as required by Engineers Australia, ABET, the UK Engineering Council, etc).

Although multidisciplinary programs such as PDE do not replace the rigour and focus of single discipline engineering programs, there appears to be a need for curricula that address the specific requirements of certain industries (e.g. NPD), and have a broader recruitment appeal. Enrolment data has revealed that the 'new' engineering discipline of Product Design Engineering is attracting significantly more women into engineering careers compared to traditional engineering courses, and as such, signifies new opportunities for greater gender balance and equity in engineering education and professional environments (refer to Section 2.8).

Whilst more traditional engineering disciplines have curricula constrained by regulatory and accreditation organisations, new multidisciplinary programs offer opportunities for faculties to respond more immediately to the needs of local industries, enhance and extend existing skills and develop new graduate attributes. However, whilst industry response has been overwhelmingly enthusiastic, PDE-style curricula occur in a comparatively small number of universities. On the other hand, consistent growth in program numbers, and the appearance of new iterations (such as RMIT's B.Eng in Electronic Product Design), is indicative of a movement towards multidisciplinary engineering education.

It has been evident, since the inception of the TU Delft IDE program over 40 years ago, that a need exists for integrated design and engineering learning. This research indicates that the multidisciplinary Product Design Engineering curriculum provides an appropriate 'engineering' (rather than design) response. As such, PDE highlights the potential of multidisciplinary learning and non-traditional engineering curricula.

[4] Measure the impact of this new engineering discipline against existing product design disciplines; in particular industrial design and mechanical engineering.

The NPD disciplines of Mechanical Engineering and Industrial Design have been compared and evaluated with Product Design Engineering, against the key graduate attributes (identified in Chapter One). These attributes required by engineers in NPD include creativity, open-ended problem solving, design skills and a user-centred approach. In this research, educators, alumni and employers have reflected on the attributes of traditional NPD disciplines, against the relatively new PDE discipline.

The research revealed that whilst mechanical engineers posses high levels of engineering science knowledge, technical understanding and analytical skills across a broad spectrum, there is insufficient development of creativity and design skills, and a lack of understanding of user needs and user-product interaction. By contrast, industrial designers whilst creative and user-focused, were found lacking in technical and manufacturing knowledge, critical analysis and engineering consideration. However, the multidisciplinary Product Design Engineers were found to be capable across all scopes of NPD activity, regardless of whether the product was user-led or technology-led

The semi-structured interviews (in Chapter 8) found that employers considered the product design engineers to have more appropriate skill-sets for employment in new product development than either industrial designers or mechanical engineers, and to be more 'industry ready'. This does not to negate the role or potential contribution of either of the established NPD disciplines. Rather indicates that the contribution of PDEs is invaluable both in small organisations, where they can fill roles typically occupied by two single-discipline employees, and in larger organisations, where interdisciplinary abilities have significant synergetic benefits to communication and collaboration.

The research also found evidence of 'weakness' in some aspects of Product Design Engineering. Compared to industrial designers, there was less creativity and high-end design and drawing skills, but more importantly the research found less engineering 'rigour' and less critical questioning when compared to mechanical engineers (refer to Section 8.6.1). This was not necessarily seen as a problem by employers as they did not employ the PDEs to do complex engineering analysis, instead valuing their interdisciplinary skills.

It also emerged that the multidisciplinary PDEs can suffer from an 'identity' crisis and are prone to professional frustration when employed in a single disciplinary role, without opportunity to fully utilise their skills (refer to Section 8.6.).

[5] Understand the benefits and shortcomings of the PDE multidisciplinary design-engineering curricula.

The research has identified significant benefits of multidisciplinary curricula. Industry and alumni responses to research questions (in Chapters 7 and 8) indicate a successful integration of the two traditionally disparate professions. The specialised new engineering discipline emerging from the PDE curricula has many benefits, especially for NPD employers, however the research has also identified some areas of concern.

Benefits

The benefits of the integration of design into engineering curricula were found to be:

- more creative and innovative engineers,
- more user-centred engineers,
- stronger cross-discipline collaboration and understanding in the workplace,
- versatility and flexibility,
- greater appeal to females than traditional engineering careers, and
- industry readiness and employability.

It appears that the multidisciplinary training of Product Design Engineering results in engineers with distinctive skill sets. The integration of design and engineering has been successful, with PDE graduates considered by industry to be highly employable, immediately effective, versatile and innovative.

Shortcomings

Whilst industry employers were enthusiastic when interviewed about the PDE graduates capabilities, the research also revealed some shortcomings resulting from the combined curriculum. Employers identified some weaknesses including:

- lack of depth in engineering knowledge,
- an identity crisis amongst graduates (designer or engineer), and
- graduate frustration due to the lack of multidisciplinary opportunities

Whilst it was felt by employers that the benefits outweighed the shortcomings, it is still evident that any multidisciplinary educational program will, by necessity, involve some compromise and will inevitably result in lack of depth across both disciplines. It is also apparent that whilst the curriculum and delivery will be relatively balanced, individual students will naturally gravitate towards one of the professions, possibly at the expenses of proficiency in both areas of activity.

[6] Identify curriculum developments in Product Design Engineering that may benefit learning in other engineering disciplines.

The global iterations of Product Design Engineering have proved more adaptive to industry needs than the more established engineering disciplines which are bound by rigid educational frameworks imposed by regulatory and accreditation organisations and industry expectations. It has become evident, through examination of global curricula (in Chapter 2), that the PDE model has a flexibility and responsiveness not possible within established engineering curricula such as Mechanical Engineering. The PDE model sacrifices depth in engineering knowledge and analysis to incorporate the design curriculum and its key agendas, but this is balanced by the resultant broad skills base and extended capabilities of graduates.

PDE’s project-based learning curricula with its fostering of creativity, through design projects and open-ended problem solving, points to new ways to develop engineering graduate capability. The experiential learning model, achieved through the design studio, affords students the opportunity to practice their skills and apply their theoretical knowledge framework to real world projects and produce tangible outcomes. This has proved invaluable in developing industry-ready graduates as is evidenced by the feedback from PDE employers (refer Chapter 8).

In addition, the deliberate fostering of design skills and creativity has resulted in engineers who are more focussed on developing unique and innovative solutions, rather than fixating on prior solutions and ‘tried-and-true’ methods. This is significant for all engineering education, if future graduates are to meet the Grand Challenges for Engineering in the 21st Century (US National Academy of Engineering 2008), and the needs of less fortunate global communities.

There is also strong evidence of the value of a user-centred approach to engineering, a trait specifically fostered in PDE programs world-wide, but not always evident in Mechanical Engineering curricula. Whilst this research has identified the parallel processes of user-led or technology-led design, it is apparent that both require consideration of the user, whether that user is the end customer, an assembly worker in a manufacturing plant, or an on-site product installation technician.

Response to research questions

[1] What graduate attributes must engineering curricula develop to prepare engineers for roles in new product development?

This research has, through review of the literature, examination of regulatory and accreditation agendas and engagement with industry, identified (in Section 1.9) twelve graduate attributes essential for engineers engaged in new product development roles:

- mechanical engineering ability,
- technical knowledge,
- product design skills,
- aesthetic styling ability,
- sustainable,
- socially responsible,
- creative and innovative,
- user-centred,
- wicked problem solving ability (critical thinking skills),
- interdisciplinary skills,
- manufacturing knowledge, and
- industry readiness for roles in NPD.

Whilst both industrial design and mechanical engineering have been found to be deficient in some of these attributes, the new discipline of Product Design Engineering addresses all aspects required for new product development (refer to Section 1.17). The integration of design curriculum develops a creative and user-centred approach, whilst maintaining sufficient rigour for an engineering qualification.

[2] Can the integration of design and engineering curricula enhance the product design capabilities of engineering students?

The research has shown that multidisciplinary engineering education can be successful in developing industry-ready graduates with broad capabilities. However curriculum compromises must be accommodated, as the key skills and knowledge for both disciplines need to be developed in a shorter time frame. There is not sufficient time to develop an engineer with the depth and rigour of a more established engineering specialisation, whilst accommodating the needs of the design curricula to develop creativity and build design acumen. A balanced curriculum is essential to ensure competency in both disciplines, and care must be taken to ensure that the graduates' interdisciplinary skills outweigh any shortcomings or lack of depth in either discipline. The challenge for engineering staff is to develop a greater appreciation of creativity and the importance of design, whilst design staff need to better understand engineering's systematic approach to design, and the need for technical rigour and critical analysis.

It is evident from the findings of this research (in Chapters 6, 7 and 8) that the addition of design curriculum agendas, such as sustainability, and socially responsible design, and the development of design acumen, including creativity, drawing, open-ended problem solving, and user-centred design, significantly enhances the skills and knowledge base of engineers, and enhances their employability. The experiential learning that occurs through the design projects, results in real-world learning opportunities not evident in theory-based curricula.

It is also evident from the examination of PDE curricula, that it is possible to successfully integrate these traditionally disparate disciplines facilitating interdisciplinary synergies and developing broader and more versatile engineering graduates. The product design engineers have been found to display high levels of creativity and design skills whilst maintaining appropriate engineering and technical competency. Industry employers (in Chapter 8) have observed greater graduate suitability for NPD roles within this new engineering discipline. This has impacted significantly on roles within design teams and on the design project responsibilities of industrial designers, whose roles have moved exclusively to the creative and aesthetic front-end, away from product resolution tasks. In addition, there are instances where PDEs have displaced both industrial design and mechanical engineering roles within organisations.

The creative user-centred design approach, imparted through the inclusion of industrial design curricula, combined with the synergetic ability to simultaneously apply the methods of both disciplines, has significant impact on product viability.
The research has found that multidisciplinary educational models, such as PDE, can develop more creative and versatile engineers whose product design capabilities far exceed those of other engineering disciplines.

[3] Is the Product Design Engineering curriculum an appropriate response to the current and future needs of new product development industries?

This research (see Chapter 8) has identified a lack of preparedness for new product development in both Industrial Design and Mechanical Engineering, when evaluated against criteria of required graduate attributes established through a review of the literature and industry consultation. It is apparent that the need for graduates with proficiency in both design and engineering can only be addressed by multidisciplinary curricula that specifically address the needs of those industries.

The Product Design Engineering curriculum is one such approach, as is the more established Industrial Design Engineering (IDE) model common across the UK and Western Europe. These curricula differ not in intent (multidisciplinary design/engineering), but rather in focus. The IDE curriculum is typically a *design* program enhanced and extended by the inclusion of engineering content, whilst the Product Design Engineering global programs are fully accredited *engineering* courses where engineering learning is enhanced by new design skills and agendas taken directly from industrial design programs.

IDE and PDE, and other variants with similar curriculum intent, make an important contribution to new product development workplaces, where interdisciplinary synergies facilitate understanding and collaboration and enable enhanced product outcomes through integration of technical and user-centred creative endeavour.

The research has identified a strong correlation between the curriculum of all surveyed PDE programs (see Chapter 2), and the key graduate attributes, as identified in chapter 1, expected of engineers in new product development industries. It is apparent that all of the global PDE programs successfully integrate design skills and critical agendas into the engineering curriculum, enhancing engineering practice and employability in new product development.

Product Design Engineering has been shown in this research to represent a new approach to the education of engineers; one that whilst not suitable for all engineering applications, addresses the concerns of engineering regulatory organisations, and has proven to be an appropriate educational response to the current and future needs of new product development.

New contribution to knowledge

This research has concerned itself with the identification, examination, analysis and documentation of an emerging global trend in engineering education; product design engineering. It is believed to be the first in-depth study of this new engineering discipline, and presents an insight into possible new directions in engineering education, in particular curricula aimed at developing engineers for specific vocational pursuits.

Based on a synthesis of the research findings it is apparent that the research has generated a number of conclusions that have implications for engineering education, including:

- clarification of the required graduate attributes for engineers engaged in new product development (through the literature review in Chapter 1, curriculum benchmarking in Chapter 2 and supported by industry feedback in Chapter 8),
- a cogent argument that supports the inclusion of design and creativity curricula, and societal and environmental agendas in engineering education, regardless of vocational intent (in Chapters 3 and 4, validated in Chapter 6),
- validation of Product Design Engineering as an appropriate response to industry expectations of engineers in new product development (supported by findings in Chapters 7 and 8).

Accordingly, the research makes a valid contribution to the field of knowledge surrounding engineering education and addresses a knowledge gap in the understanding of the new engineering discipline of Product Design Engineering.

Reflections of the strengths and limitations of the research

Strengths

I have been fortunate during the research, through my position as Program Coordinator of the Swinburne PDE program, to have had unlimited access to students, lecturers and alumni, course statistical evidence and teaching activities in design studios.

In addition, I have been in a position to direct the curriculum as the research developed and use design studios and student activity to test hypotheses. Both the SketchFest drawing curriculum initiative (described in Case Study 2) and the evaluation of design and problem solving ability (Chapter 6) are examples where this research both responded to, and influenced the curriculum.

The external research, in particular the global curriculum survey (in Chapter 2), the alumni survey (Chapter 7) and the interviews with employers of Swinburne PDE graduates (in Chapter 8) would not have been possible without the extensive network of contacts within academia and the product design industry that I have established during fourteen years of professional practice, and ten years of research and teaching in product design. As a result, the research has benefited from critical industry feedback, engagement with globally distributed academics and relationships with professional product design engineers, all of which have produced the evidential data that underpin the research findings.

The survey of PDE alumni, combined with the semi-structured interviews of their employers, across a range of product development and manufacturing industries, provided evidence of the success of the Product Design Engineering discipline in Australia. These results were supported by feedback from global program leaders which balanced the Australian findings with international information in regard to graduate skills, career pathways and industry relevance.

Limitations

There has been little previous research undertaken to examine the Product Design Engineering discipline and as such there are very few publications describing the pedagogy. However, there are significant research publications and industry reports that identify the need for revision of engineering curricula and enhanced graduate attributes; these have formed the basis of the inquiry.

Access to global course data and enrolment and employment statistics could only be accessed through third parties, and it was not possible within the scope of this research to engage directly with either international PDE graduates or interview global PDE employers. As such, whilst efforts have been made to ensure that examples of student design outcomes are representative of all global PDE programs, some examples and evidence are by necessity Australian-based and may be somewhat Melbourne-centric. This does not diminish the findings as they are supported by global evidence, however it would have been preferable to undertake all of the evidentiary research on an international level, and to compare data from local and global contexts.

As the researcher was embedded within a Product Design Engineering program it could be suggested that neutrality of the research was not always possible. However, whilst the results are supportive of this new engineering discipline, research findings are strongly supported by evidence from industry employers and are consistent with global data. The research did highlight some areas of concern (e.g. lack of engineering depth and rigour and an identity crisis in PDE graduates) and these should be pursued in further studies.

Suggestions for future research

It would be beneficial if a detailed study of other institutions could be undertaken with the rigour of the examination of Swinburne Product Design Engineering included in this thesis. In particular, it would be advantageous to reflect on statistical and empirical data from other Product Design Engineering programs and compare those findings with data from other multidisciplinary curricula such as Industrial

Design Engineering. In future research, curriculum initiatives from Product Design Engineering could be adapted to other engineering disciplines, and improvements in creativity, open-ended problem solving, and human-centred and responsible practice observed. That however, is outside the scope of this research.

Concluding remarks

The aim of this research was to investigate the emerging engineering discipline of Product Design Engineering as appropriate training for engineers engaged in new product development roles. In the NPD environment, where engineering education has previously been criticised for not developing creative or human-centred graduates, the PDE curriculum appears to represent a more suitable approach to engineering education.

The design project-based curriculum affords new learning opportunities and student motivating factors and experience in the practice of engineering in a real world context. The development of specific skills in design, creativity and responsible practice appears to have 'humanised' engineering learning and as such has proven to be significantly more appealing to the female demographic than traditional engineering pathways. These multidisciplinary curricula have implications for other engineering educational programs, in that they directly address the concerns of engineering regulatory organisations, in terms of the skills and graduate attributes required to address the challenges of 21st century engineering.

This research, as a detailed examination of the new engineering discipline of Product Design Engineering, contributes to previous research into engineering education, by highlighting the advantages of multidisciplinary learning, and the benefits of the inclusion of design curricula in engineering learning.

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Appendices

1. **SUHREC Project 2009/168: Survey of Product Design Engineering Curriculum**
    - Ethics approval
    - Survey questions

2. **SUHREC Project 2010/038: Survey of Product Design Engineering Graduates**
    - Ethics approval
    - Survey questions

3. **SUHREC Project 2010/042: Interview of employers of Product Design Engineering graduates**
    - Ethics approval
    - Consent information statement
    - Informed Consent form
    - Interview questions

Appendix 1

SUHREC Project 2009/168

Survey of Product Design Engineering Curriculum

Ethics Approval

From: Anne Cain
To: Melles, Gavin
CC: Kapoor, Ajay; Wilkins, Keith; de Vere, Ian
Date: 19/08/2009 3:41 PM
Subject: SUHREC Project 2009/168: Ethical Clearance

To: Dr Gavin Melles and Mr Ian de Vere, Design, and Prof Ajay Kapoor, FEIS

Dear Gavin, Ian and Ajay

2009/168Survey of Product Design Engineering Curriculum and Pedagogy – as part of PhD research entitled "Developing a Creative and Human-Centred Approach to Engineering Design"**Dr Gavin Melles Design Mr Ian de Vere Prof Ajay Kapoor FEIS**
Approved Duration: 19/08/2009 To 01/02/2010

I refer to the ethical review of the above project protocol carried out on behalf of Swinburne's Human Research Ethics Committee (SUHREC) by a SUHREC Subcommittee (SHESC3). Your responses to the review, as emailed on 19 August 2009, were put to a delegate of the Subcommittee for consideration.

I am pleased to advise that, as submitted to date, the project may proceed in line with standard on-going ethics clearance conditions here outlined.

- All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the National Statement on Ethical Conduct in Human Research and with respect to secure data use, retention and disposal.

- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.

- The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/ clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

- At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project.

- A duly authorised external or internal audit of the project may be undertaken at any time.

Please contact the Research Ethics Office if you have any queries about on-going ethics clearance, citing the SUHREC project number. A copy of this communication should be retained as part of project record-keeping.

Best wishes for the project.

Yours sincerely

Anne Cain
Secretary, SHESC3
Swinburne University
FBE Research Office -H95
Lvl 6, 60 William St
Hawthorn 3122
Ph: 9214 8605
ancain@swin.edu.au

SUHREC Project 2009/168:
Survey of Product Design Engineering Curriculum and Pedagogy

Institution and Course details

1. **Please insert your University and Course details**

Name of University / Institution:

Name of Faculty / School offering the course:

Course name:

Role of person completing this survey (course coordinator, lecturer etc)

Link for web-access to course curricula

Your name (optional - for contact purposes only, your name will not be linked to results)

2. **Degree awarded and course exit points**:
(select multiple options as appropriate)

- ☐ B.Eng. (3 years)
- ☐ B.Eng. (Hons) (4 years)
- ☐ M.Eng. (5 years)
- ☐ B.Sc. (3 years)
- ☐ B.Sc. (Hons) - (4 years)
- ☐ M.Sc. (5 years)
- ☐ other (please specify)

3. **Normal duration of course (most common student experience)**

- ○ 3 years
- ○ 4 years
- ○ 5 years
- ○ other

4. **Course accreditation with industry regulatory bodies.**

Please specify the level of professional accreditation of your graduates.
Are graduates eligible for:

- ○ professional engineer (full membership)
- ○ engineering technologist
- ○ associate member (engineering officer)
- ○ please specify accrediting body ☐

5. **Establishment of program / course**

In what year did this course commence (1st year of student intake)? ☐

No. of graduates from the course so far (include 2009 figures) ☐

Student Demographics and Retention

6. **Student demographics**

Student intake per year ☐

Percentage of female students ☐

7. **Student retention**

What percentage of students leave the course before completion ☐

What percent of these are female? ☐

How do these retention rates compare to other engineering course within your faculty?

○ lower ○ similar ○ higher

Curriculum

8. **Course multidisciplinary content**

Comparison of engineering and design subject loading
- please specify as % of total course subjects

design content % [ ]

engineering content% [ ]

other non-core subjects (electives / minors etc) % [ ]

9. **Curriculum delivery** - how are the two disciplines (engineering and design) taught?

- ○ same faculty
- ○ different faculties
- ○ different institutions (co-offered by two universities)

10. **Briefly explain how engineering and design culture is integrated into the course structure.**
(e.g. cross-faculty learning, industry engagement, shared subjects with other disciplines, interest groups, SAE car etc)

11. **Content integration**

Is there integration between the content and delivery of the engineering and design subjects?

- ○ yes
- ○ no

please explain

12. **Design Curriculum**

At what stage of the course do the students commence design subjects?

- ○ year 1
- ○ year 2
- ○ year 3
- ○ year 4

13. **Design communication tools** - Sketching / Drawing / Rendering

Are students/graduates expected to be fluent/proficient at drawing?

- ◯ yes - must achieve proficiency during their studies
- ◯ yes - must achieve proficiency by graduation
- ◯ no - not considered essential

please provide any additional comments

14. **Design projects**

Is engineering science incorporated into design teaching and design project outcomes?

- ◯ yes
- ◯ no

Please elaborate briefly

15. **Design criteria -** curriculum delivery

Does the curriculum include significant learning in the following areas:

- ☐ sustainable design
- ☐ socially responsible design
- ☐ user centred design
- ☐ product interaction / interface design
- ☐ inclusive design
- ☐ ergonomics and human factors

16. Engineering curriculum

Are engineering subjects unique to the PDE course or shared with other engineering courses?

- ◯ unique to PDE course
- ◯ shared with other engineering courses (such as Mech. Eng)
- ◯ other

17. Engineering curriculum continued

Is engineering design specifically taught in the core curriculum?

yes

no

If specifically taught, explain how. (lectures/ design projects - name of subject(s)

18. Engineering curriculum

Do PDE students experience project based learning in engineering subjects?

If yes, please explain

yes often

rarely

no (only in design subjects)

19. **How is creativity fostered in your students through curriculum activities?**

design projects

ideation exercises

solution focussed activity

open-ended problem solving

ill-defined problem framing and solving

other (please specify)

20. **In which learning areas is creativity fostered?**

design subjects

engineering subjects

both

21. **Are your students**

expected to be creative and innovative?

comfortable with poorly-defined problems and uncertainty?

proficient in design?

22. Human-centred/ User-centred design
Are students specifically taught the principles of human-centred design or inclusive design?

yes no

23.	**Do projects typically involve user considerations or mostly functional considerations?**

- mostly user needs
- mostly functional requirements
- always both

24. **Are students required to demonstrate knowledge and application of the following in their design outcomes?**
(you may select more than one)

- sustainable design
- socially responsible design
- user-centred design
- cultural understanding
- socio-economic implications

Industry relevance

25. **Industry feedback**

How is industry involvement (in the development of your curriculum) achieved?
(you may select more than one)

- Industry based learning / internships/ placement
- industry led projects
- industry advisory panel
- industry involved in teaching
- other (please specify)

26. **Course recognition in industry and community**

As a relatively new curricula/ profession, how well in product design engineeing known and understood in:

(please select one option per row)

	not known	known but not understood	known and understood	respected
industry				
community				
schools				
engineering regulatory bodies				

27. **Please explain key areas where your engineering course has received commendation from industry.**

(e.g. graduate skills, attributes or employability, industry relevant curricula, creativity, sustainability, social responsibility, design acumen etc)

28. **Graduate pathways**

What percentage of you graduates find employment in their chosen field?

- more than 80%
- 60 - 80%
- 40 - 60%
- less than 40%

29. **In which industries do your graduates typically find employment?**

- product design and development
- engineering design
- manufacturing
- production engineering
- automotive
- mining
- other (please specify below)

30. **How do you promote graduates to industry?**

- highly competent design engineers
- engineers with design accumen
- product / industrial designer
- designers with engineering knowledge/ability
- multidisicplinary professionals (capable in both fields)
- other (please specify)

31. **Do you specifically focus the course and projects towards any particular industry?**
(e.g. to enhance employment opportunities / towards local industries etc)

no

yes

yes (if yes - please specify industry and why)

32. **Industry engagement and collaboration**
Do students engage with industry partners on real world or industry-led projects as part of the curriculum?

yes often

occasionally

no

please provide examples of projects and industry

33. **Industry placements**
Are students placed in internships (paid employment) in industry during the course?

yes - as part of core curriculum

yes - optional

no

if yes, please specify duration of placement

Graduate attributes

34. **Briefly identify expected graduate skills sets resulting from the PDE course**

creative	human-centred	adaptable	flexible
responsible	sustainable	design acumen	engineering proficiency

other (please specify)

35. **In your opinion, how do Product Design Engineering graduates differ from Mechanical Engineers and Industrial Designers?**

I thank you for the time you have dedicated to the completion of this survey.

As educators involved in the unique and special area of interdisciplinary education, the sharing of knowledge and experience is an important tool in pedagogical development and your contribution is invaluable. During the data collation and evaluation process, it may be beneficial to contact you directly with specific questions relating to your program. If you are amenable to being contacted at a later date, please supply your contact details in the space provided below – your name will not be linked to the survey results.

Once again thank you for your time and contribution.

Ian de Vere
Program Coordinator of
Industrial Design and Product Design Engineering
Swinburne University of Technology
Melbourne, Australia

idevere@swin.edu.au
+61 3 9214 6877

Finish

Appendix 2

SUHREC Project 2010/038

Survey of Product Design Engineering Graduates

Ethics Approval

From: Ann Gaeth
To: Melles, Gavin
CC: Resethics; de Vere, Ian
Subject: SUHREC Project 2010/038 Ethics Clearance

Wednesday - April 21, 2010 11:04

To: Dr Gavin Melles; Mr Ian de Vere

Dear Dr Melles,

SUHREC Project 2010/038 Survey of Product Design Engineering Graduates - as part of PhD research entitled "Developing a Creative and Human-Centred Approach to Engineering Design"

Dr Gavin Melles Design, Mr Ian de Vere
Approved duration: 21/04/10 To 31/12/10 [adjusted]

Ethical review of the above project protocol was undertaken on behalf of Swinburne's Human Research Ethics Committee (SUHREC) by a SUHREC Subcommittee (SHESC3) at a meeting held 16 April 2010.

I am pleased to advise that, as submitted to date, the project may proceed in line with standard on-going ethics clearance conditions here outlined.

- All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the current National Statement on Ethical Conduct in Research Involving Humans and with respect to secure data use, retention and disposal.

- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.

- The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/ clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

- At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project.

- A duly authorised external or internal audit of the project may be undertaken at any time.

Please contact me if you have any queries about on-going ethics clearance. The SUHREC project number should be quoted in communication. Chief Investigators/Supervisors and Student Researchers should retain a copy of this email as part of project record-keeping.

Best wishes for project.
Yours sincerely,

Ann Gaeth
Secretary, SHESC3

****

Dr Ann Gaeth PhD
Administrative Officer (Research Ethics)
Swinburne Research (H68)
Swinburne University of Technology
P.O. Box 218
HAWTHORN VIC 3122
Tel: +61 3 9214 5935 Fax: +61 3 9214 5267

SUHREC Project 2010/038

Survey of Product Design Engineering Graduates

Welcome PDE Alumni.

Thank you for participating in this survey of Product Design Engineering graduates.

The purpose of the survey is to measure the impact of the PDE program through analysis of graduate pathways and career progression, and comparison between Product Design Engineering, Mechanical Engineering and Industrial Design graduates in the workplace.

Results from this survey will contribute to ongoing research into new and innovative engineering curricula and will assist in the future refinement of the Swinburne PDE curricula. As graduates of the PDE course, your feedback is essential to validate and improve this unique engineering curriculum.

This survey is completely anonymous, and your responses to this survey are confidential and will be used for no other purpose than a measure of the success of the PDE curriculum. At no time will respondent's names be linked to reported or published results. However if you are interested in being further involved in this research through an interview process, there is provision at the end of the survey for you to indicate availability and supply your contact details.

It is expected that completing this survey will take no more than 15 minutes.

Thank you for your continued support of the PDE program and your valuable contribution to this research.

Ian de Vere
Program Coordinator,
Product Design Engineering and Industrial Design,

Faculty of Design,
Swinburne University of Technology
idevere@swin.edu.au
+61 3 9214 6877

Please note that completion of this questionnaire is taken as your Informed Consent to participate in this research. Informed Consent in this instance means that you clearly understand the rational of this research, that your participation is voluntary, that you are under no obligation to reveal your identity and you acknowledge that the resulting data will be used for the purposes of ongoing research into product design engineering curricula and as such may be reported in publications suchas conference proceedings and academic journals.

This project has been approved by or on behalf of Swinburne's Human Research Ethics committee (SUHREC) in line with the National Statement on Ethical Conduct in Human Research. If you have any concerns or complaints about the conduct of this project, you can contact:

Research Ethics Officer, SwinburneResearch (H68)
Swinburne University of Technology, POBox 218, HAWTHORN VIC 3122
Tel (03) 9214 5218 or +61 3 9214 5218 or resethics@swin.edu.au

Career pathways

1. **Personal details**:

   Year of course completion:

   Current employment

   role

   employer

   industry

   How long after completing the course did you secure employment (in your chosen field)

   Gender:

   - male
   - female

2. **Briefly describe your areas of responsibility**

3. **Briefly describe previous employment positions**

4. **What aspects of the PDE course have been most valuable in your career?**
   (select appropriate options or specify if not listed)

   - design skills
   - multidisciplinary ability
   - user-centred focus
   - creative problem solving
   - sustainability
   - socially responsible design
   - project based learning
   - industry based learning

international exchange

other - please specify

5. **As a Product Design Engineer, what skills or attributes do you possess that are distinct from industrial designers or mechanical engineers?**

comparison of skills with other engineers

How do you measure your skills and attributes against other professionals in your field?

(For the following questions use the appropriate response scoring based on the following)

1. strongly disagree
2. disagree
3. there is no difference
4. agree
5. strongly agree

6. **As a PDE, I am more creative than other engineers**.

	1	2	3	4	5	
strongly disagree						strongly agree

7. **My design skills (especially sketching ability) enable me to develop concepts and design solutions more effectively than other engineers.**

	1	2	3	4	5	
strongly disagree						strongly agree

8. **I am more aware of (and responsive to) user needs than other engineers**

	1	2	3	4	5	
strongly disagree						strongly agree

9. **I am more sustainable in my professional work than other engineers.**

1 2 3 4 5

strongly disagree ◯ ◯ ◯ ◯ ◯ strongly agree

10. **I am more socially responsible than other engineers.**
(e.g. more aware of the impact of my professional activities, ethical in approach, more considerate of cultural and humanitarian issues, engage in socially responsible design (SRD) to improve human well-being and livelihood)

	1	2	3	4	5		N/A
Poor	◯	◯	◯	◯	◯	Excellent	◯

11. **I am more involved in the early (front end) stages of product development than other engineers.**
(e.g. conceptual design, product planning and ideation, etc)

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agree

12. **My multidisciplinary knowledge and skills enables me to effectively liaise with different professions**.

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agree

13. **PDE has a broad curriculum with specialist teaching in both design and engineering.**
What else would you like to see included in the curriculum?

14. Course awareness: PDE is a relatively new curricula and career.

Have you encountered a lack of awareness or understanding of the course and graduate attributes in industry?
Has this been impeded you career progression?

(If yes, please explain).

Thank you for completing the survey - have you answered all questions?

I thank you for the time you have dedicated to the completion of this survey.

Your contribution is invaluable, and will greatly assist the development of Product Design Engineering, both as an educational program and as a profession.
During the data collation and evaluation process, it may be beneficial to contact you directly with specific questions relating to your program. If you are amenable to being contacted at a later date, please supply your contact details in the space

provided below – your name will not be linked to the survey results.

Once again thank you for your time and contribution.

Ian de Vere
Have you answered all questions?

Please note that clicking on 'FINISH' below will complete the survey **only if all questions have been answered**. You should see a thank you screen to confirm that the survey is completed and saved.

If the survey returns to the start, this will indicate that your responses are incomplete - in this case scroll down the survey - the unanswered question will request a response.

Appendix 3

SUHREC Project 2010/042

Interviews of employers of Product Design Engineering graduates

Ethics Approval

From: Ann Gaeth
To: Melles, Gavin
CC: Resethics; de Vere, Ian
Subject: SUHREC Project 2010/042 Ethics Clearance

Wednesday - April 21, 2010 11:10 AM
To: Dr Gavin Melles; Mr Ian de Vere

Dear Dr Melles,

SUHREC Project 2010/042 Interview of employers of Product Design engineering graduates - as part of PhD research entitled "Developing a Creative and Human-Centred Approach to Engineering Design"

Dr Gavin Melles Design, Mr Ian de Vere
Approved duration: 01/05/10 To 31/12/10

Ethical review of the above project protocol was undertaken on behalf of Swinburne's Human Research Ethics Committee (SUHREC) by a SUHREC Subcommittee (SHESC3) at a meeting held 16 April 2010.

I am pleased to advise that, as submitted to date, the project may proceed in line with standard on-going ethics clearance conditions here outlined.

- All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the current National Statement on Ethical Conduct in Research Involving Humans and with respect to secure data use, retention and disposal.

- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.

- The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/ clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

- At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project.

- A duly authorised external or internal audit of the project may be undertaken at any time.

Please contact me if you have any queries about on-going ethics clearance. The SUHREC project number should be quoted in communication. Chief Investigators/Supervisors and Student Researchers should retain a copy of this email as part of project record-keeping.

Best wishes for project.
Yours sincerely,

Ann Gaeth
Secretary, SHESC3
****
Dr Ann Gaeth PhD
Administrative Officer (Research Ethics)
Swinburne Research (H68)
Swinburne University of Technology
P.O. Box 218
HAWTHORN VIC 3122
Tel: +61 3 9214 5935   Fax: +61 3 9214 5267

Consent Information Statement

Project Title: “Interviews of employers of Swinburne Product Design Engineering graduates.”

Investigators

Dr Gavin Melles
Ian de Vere
Faculty of Design, Swinburne Univeristy of technology

Introduction to Project and Invitation to Participate

This interview is part of ongoing research into innovative engineering curricula and will supplement graduate surveys and international curriculum benchmarking.
As an employer of Swinburne Product Design Engineering graduates, your participation is vital to the assessment of the program and the comparison of graduate skills.

What this project is about and why it is being undertaken

The purpose of this interview is to ascertain whether curriculum objectives for the product design engineering program are effective and relevant to industry.

Project and researcher interests

The findings of this research project will mainly contribute to Ian de Vere’s PhD research into innovative engineering curricula, which involves extensive investigation into the Product Design Engineering paradigm. Findings may also be used to further develop the Swinburne PDE curriculum.

What participation will involve – time, effort, resources, costs, compensatory payments, etc

The research will involve an interview which should take approximately 30 minutes to complete.
It consists of both open-ended and agree/disagree questions and aims to discover the impact of product design engineering on your workplace.

Participant rights and interests – Risks & Benefits/Contingencies/Back-up Support

This research will contribute to enhanced methods of engineering education with a focus on responsible, sustainable and creative real world problem solving. Whilst the research findings will contribute to the researcher’s PhD thesis, it is also expected that the findings will provide evidence of new educational approaches that will be of benefit/interest to those involved in engineering and design education, and in relevant industries.

Resultant publications on this subject will contribute to raised community and industry awareness of the program and may enhance graduate opportunities. The opportunity exists for the findings to contribute to curriculum development for the Swinburne PDE program and other engineering curricula, and for new synergies with industry to be established.

There are no inherent risks for participants in the interview process and results and findings will be reported anonymously. Responses will be confidential and not attributable to either the participant or their organisation.

Participant rights and interests – Free Consent/Withdrawal from Participation

You have been selected for participation in this interview process as you are in a unique position to comment on the skills and attributes of graduates of Swinburne's Product Design Engineering program. As an employer of PDE graduates, your feedback is invaluable as we seek to measure and evaluate the success of this new engineering discipline.

Please note that participation in this interview process is voluntary, and participants are free to withdraw at any time without explanation. Completion of the supplied Informed Consent Form is taken as your Informed Consent to participate in this research. Informed Consent in this instance means that you clearly understand the rational of this research, that your participation is voluntary, that you are under no obligation to reveal your identity and you acknowledge that the resulting data will be used for the purposes of ongoing research into product design engineering curricula and as such may be reported in publications such as conference proceedings and academic journals.

Participant rights and interests – Privacy & Confidentiality

This interview is being recorded for accuracy of records only – participant's identity and organisation will not be linked to either interview transcripts or published results.

Whilst it is necessary for you to complete and sign the Informed Consent form, this does not in any way, link your responses to interview questions to your identity. Consent forms will be stored in appropriate secure storage within the Faculty of Design research archives.

Responses to the interview questions will be transcribed into text and the original audio recording will then be erased. Participants' responses will not be linked with individual identity in any format.

Research output

Findings of this interview process will be used, in conjunction with other research findings, to contribute to Ian de Vere's PhD thesis which investigates new and innovative engineering curricula. It is also expected that research outcomes will be published in academic journals and in conference proceedings. The research will contribute to enhanced methods of engineering education with a focus on responsible, sustainable and creative real world problem solving, and to further development of the PDE curriculum.

The research seeks to find commonality and trends regarding product design engineering in industry.
Whilst you are asked to give qualitative responses to specific questions based on your experience and observations, in no way does this research involve the collection of personal or confidential data and at no stage will the identity of any participant be revealed or used.

Further information about the project – who to contact

If you would like further information about the project, please do not hesitate to contact:
Dr Gavin Melles
Head of Academic Group
Faculty of Design
Swinburne University of Technology
144 High Street
Prahran Vitoria 3144
+61 3 9214 6851
gmelles@swin.edu.au

Concerns/complaints about the project – who to contact:

This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the *National Statement on Ethical Conduct in Human Research*.
If you have any concerns or complaints about the conduct of this project, you can contact:

Research Ethics Officer, Swinburne Research (H68),
Swinburne University of Technology, P O Box 218, HAWTHORN VIC 3122.
Tel (03) 9214 5218 or +61 3 9214 5218 or resethics@swin.edu.au

Informed Consent Form (sample)

Swinburne University of Technology

Project Title: Interviews of employers of Swinburne Product Design Engineering graduates

Principal Investigator(s): Dr Gavin Melles, Ian de Vere

1. I consent to participate in the project named above. I have been provided a copy of the project consent information statement to which this consent form relates and any questions I have asked have been answered to my satisfaction.

2. In relation to this project, please circle your response to the following:

▪ I agree to be interviewed by the researcher	**Yes**	**No**
▪ I agree to allow the interview to be recorded by electronic device	**Yes**	**No**
▪ I agree to make myself available for further information if required	**Yes**	**No**

3. I acknowledge that:

   (a) my participation is voluntary and that I am free to withdraw from the project at any time without explanation;

   (b) this Swinburne research project is for the purpose of research and not for profit;

   (c) the recording of this interview is for accurate transcription of results only and will be erased after transcription of responses.

   (d) my identity, and that of my organisation, will not be linked to my responses in any format.

   (e) my anonymity is preserved and I will not be identified in publications or otherwise at any time.

By signing this document I agree to participate in this project.

Name of Participant: ……………………………………………………………………………

Signature & Date: ……………………………………………………………

Interview questions

Interviews with employers of Swinburne Product Design Engineering (PDE) graduates

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Preamble: Product Design Engineering has innovative engineering curricula, that is:

- interdisciplinary through integration of industrial design and mechanical engineering,
- fosters creativity through open-ended problem solving and a focus on design,
- and promotes sustainable and socially responsible design

The purpose of this interview is to ascertain whether curriculum objectives for the product design engineering program are effective and relevant to industry. Of particular interest are the key areas of multidisciplinary skills, creativity, design acumen, sustainability and social responsibility. As an employer of PDE graduates, your feedback is invaluable as we seek to measure and evaluate the success of this new engineering discipline. This interview is being recorded for accuracy of records only – participant's identity and organisation will not be linked to either interview transcripts or published results.

Organisation: (optional)...

Industry (main areas of activity): ....

Firstly I would like to ask you some general questions regarding the contribution that product design engineering (PDE) graduates make to your workplace.

1. What are the strengths and weaknesses of Swinburne PDE graduates?
2. Why would you employ a PDE rather than a Mechanical Engineer or an Industrial Designer? (Prompt: what are the key differences between PDE, Mechanical Engineering and Industrial Design e.g. creativity, multidisciplinary, human centred, responsible etc)
3. What contribution do PDEs make to the product design and development process in your organisation? (Prompt: typical roles for PDE graduates in your organisation e.g. front-end design, production eng.)
4. The PDE curriculum focuses on creativity and design skills. What are the benefits and implications for the engineering or design teams in your organisation?
5. Career progression – moving away from graduate skills, how well do PDE graduates progress in your organisation (compared to designers and Mechanical Engineers)?
6. PDE has proved attractive to female students (25%) compared to other engineering disciplines. Have you employed female PDEs? Have you employed other female engineers?

I would like to ask you six, *quick answer, agree/disagree questions* – similar questions have been asked of PDE graduates. It will be interesting to correlate the answers from both parties. Please feel free to expand on your answer or take a neutral position.

- PDE graduates are more creative than other engineers – do you *agree or disagree*
- PDE design skills (especially sketching ability) enable them to develop concepts and design solutions more effectively than other engineers. - *agree/disagree*
- PDE graduates are more aware of user needs than other engineers - *agree/disagree*
- PDE graduates are more sustainable than other engineers. - *agree/disagree*
- PDE graduates are more socially responsible than other engineers. - *agree/disagree* (e.g. more aware of the impact of their professional activities)
- The multidisciplinary knowledge and skills of PDE graduates enhances their liaison skill - *agree/disagree*

Is there anything else you would like to add at this point?

To conclude this interview, I would like you to describe a Swinburne Product Design Engineer, in one word....

Thank you for your time.