Integrating Design into an Alternative Engineering Curriculum

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Abstract: *Traditionally, engineering design has been considered to be the core of engineering education. This has been reiterated more recently with the joining of design curriculum to the initial formation of graduate capabilities by making explicit what has often been implicit in design papers all along – teamwork, problem solving, time constraints, interpretation of client and engineering constraints, aesthetics of design etc. More recently, alternative engineering curriculum have been developed responding to both interdisciplinary developments in engineering and redefinition of engineering roles away from traditional discipline specialisation. The core requirement of design remains both from the perspective of validation of 'new' or 'hybrid' engineering degrees and the ability to bring 'real-world' scenarios inside the classroom. This paper outlines how this challenge to remain 'true' to engineering's traditional focus of design education particularly for mechanical engineers, while working with an over-full 'hybrid' curriculum, is being resolved in the Bachelor of Engineering programme at Auckland University of Technology. Feedback and advice are sought in order to help deliver significant student learning experience.*

Keywords: *Design, methodology, curriculum development*

Introduction

Engineering design continues to be an emerging discipline (Samuel & Weir, 2000). Most learning institutions offering courses in engineering have grappled with the nature of engineering design experience to be offered to students with varying outcomes. The history and structure of design teaching in traditional mechanical engineering degrees accounts for a significant amount of the overall teaching content, for example, design accounts for 15% of overall teaching content in University of Auckland mechanical engineering, and there is a design class in every semester of the undergraduate degree course (Siedel et al, 2002). As other alternative (to traditional) undergraduate degrees have emerged the focus of design as a traditional core competency has remained. These 'new' degrees and hybrid disciplines have required a rethink of precisely how to teach design in relation to their revised curriculum content and more over, exactly what design enables a graduate engineer to learn. For instance, the recent BE in Mechatronics at Deakin University acknowledges the fundamental requirement of design but it is only incorporated as a core unit at the fourth level.

Engineering design is widely understood as providing the integration of theoretical knowledge, skills and practical elements (such as engineering standards and realistic constraints such as manufacturability) of an undergraduate degree. More latterly, design has been seen as providing space for graduate attributes to be developed (eg Messer, 2001). Increasingly, design projects are group endeavours where the development of graduate capabilities in teamwork and communication are incorporated as part of the 'project' outcomes (Hadgraft & Prpic, 2002). In a similar way, design has become the focus for the inclusion of sustainability, environmental, economic, political social and ethical issues within learning outcomes. In fact, we can do everything through design projects!!

At the professional level, the inclusion of design in an undergraduate programme in relationship to graduate competencies, technical content and demonstration of professional skills is required for accreditation of an engineering degree. The Institute of Professional Engineers of New Zealand (IPENZ) state 'the curriculum shall include engineering synthesis or design and related project work'. Further, core unit requirements for membership specify graduate attributes in the areas of planning/design, communication and ethics amongst others.

Bachelor of Engineering Degree at Auckland University of Technology (AUT)

The mechanical engineering degree at AUT was established as a manufacturing and production engineering degree; that is, the focus was not a traditional mechanical degree. The degree offers specialties in the growing areas of manufacturing management, automation and control systems. The proposed graduate employment roles are oriented towards project engineer and/or production engineer rather than design engineer.

The programme has adopted an approach to curriculum design that emphasises the developmental nature of the attributes necessary for good designers on one hand, and the variation of our unique graduate profile in relation to a 'traditional' mechanical engineering graduate on the other. Hence, aspects of design are integrated through our programme, not simply in the 'design project' format, but throughout a number of papers at different levels as in Table 1. Features of the degree programme relating to design include:

Year	Features of academic programme
First	Engineering computing; engineering science principles; engineering mathematics; communications and graphics
Second	Engineering science principles, manufacturing technology, engineering modelling, projects (eg design and build self propelled vehicle)
Third	Engineering economics; systems analysis, mechatronics and automation, projects
Fourth	Design methodology; industrial project in conjunction with work placement; ethics and sustainability; advanced manufacturing technology; OM

Table 1: Design–related components in AUT Bachelor of Engineering curriculum

Design Pedagogy

The pedagogical approach to design aims to provide a 'real-world' learning environment in which students can integrate knowledge and which provides opportunities for deeper and more meaningful learning to occur through a guided learning experience. Our enthusiasm for real-world learning has, to some extent, been balanced with the realities of our real-world classrooms as indicated in the following: capabilities, lack of 'engineering' experience, learning styles.

Capabilities

Firstly, our experience suggests the development of graduate capabilities must be addressed across the curriculum, not simply for instance, in the isolation of a single 'group' project. We have previously discussed the integrated approach (both in teaching and learning approaches and assessment) adopted in the programme to develop group or team work capabilities (Stonyer, Dodd et al, 2001). This approach begins in informal tutorial groups in the first year, continuing through to design project challenge groups in latter years.

Engineering experience

Secondly, many design texts refer to the elusive (for undergraduate students in the main) work of 'experience and heuristics' (Samuel & Weir, 2000) in the process of design. For most of our students with limited exposure to the manufacturing/production engineering industry, 'experience' is severely limited. This requires us as educators to reflect on how and what we teach in engineering design. It also challenges us as educators to focus on describing 'what is going on in our heads' when we are doing design – that is making the implicit of experience and heuristics explicit where possible.

This approach differs from the more 'traditional' design project scenario based on either project-assisted approaches (viz the 'old' approach) or student-centered problem based learning pedagogy (viz the 'new' approach) (Hendy & Hadgraft, 2002, p133). While supportive of a problem based learning approach, it does have disadvantages relating to:

- removing the need for students to be 'pre-trained'- an outcome of the project-assisted approaches (ibid);
- weaker specialist knowledge and
- weaker technical methodology (Kjersdam & Enemark 1994)

Often, it is precisely this 'pre-training' phase that provides both specialist knowledge and methodological rigour. 'Pre-training' to achieve these goals may well be considered a necessity by educators given the time constraints of an engineering degree and increasing pressures of meeting the vast range of learning outcomes to be met. Part of our role, therefore, is to engage students in a variety of learning modes, which facilitate understanding the methodology of design and how to identify and utilise existing processes/procedures available in engineering, while at the same time accommodating their limited experience.

Learning Styles

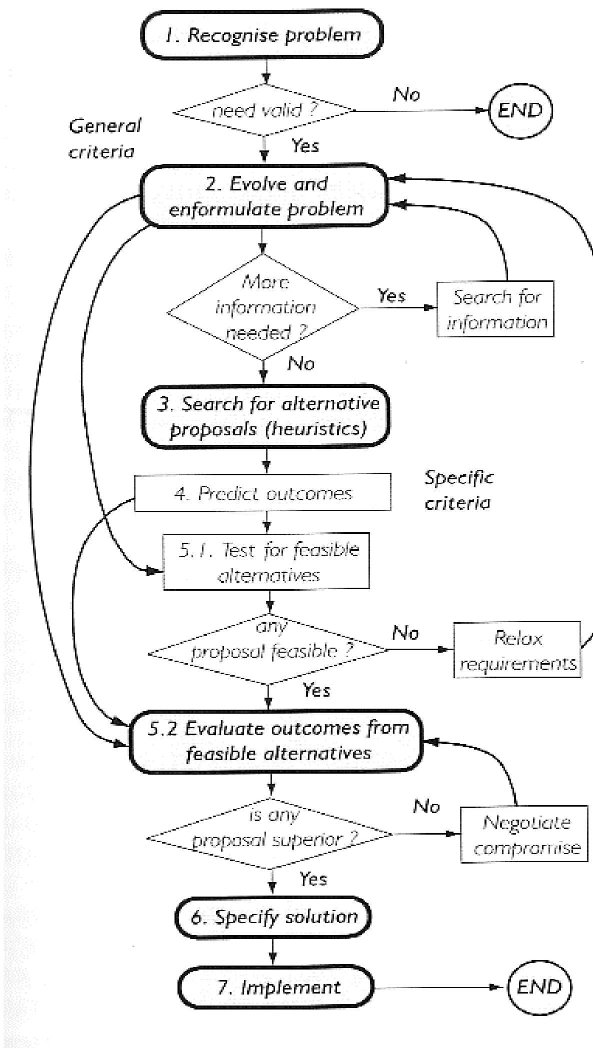
Thirdly, the focus in tertiary education over the last 10 years on 'student-centered learning' requires us as educators to recognise students enter our classrooms with a range of learning styles (Cropley, 2001). Hendy & Hadgraft (op cit) found that students preferred learning styles in a specific problem based learning context, were predominantly 'seeks solutions to problems' and 'seeks intellectual comprehension'. However, not all were analytical learners – a finding which suggests that students may need learning contexts which focus on the skills of analysis and synthesis essential in the solution of design problems. Consequently teaching methods particularly in relation to design should accommodate a range of learning styles by initially guiding students to strategies, resources and learning materials which support the generation of realistic solutions to engineering problems and then to problems in which the process and solution are totally student driven.

Design Methodology

The paper 'Design Methodology' in the fourth year of the degree is part of an overall approach to the development of design skills and capabilities. It covers the process of design as a problem-solving, decision making, creative and optimising activity. Course content includes design philosophy, methodology and procedures. It deals with the creation of solutions to fulfil an engineering need, and is a synthesis of material studied in earlier modules (eg. design against failure, materials selection, fatigue, etc.). Assessment items specifically address the engineering genres of report writing, case study presentations (both oral and written including posters) and design development review.

The paper seeks to demonstrate how engineers solve problems through design methodology, not as a preset series of steps, but rather as a methodological approach – a 'roadmap' (Dym & Little, 2000, p22) - incorporating contemporary and appropriate tools available for the solution of engineering problems. Hence, the paper specifically identifies and addresses the weakness in technical methodology identified in some student centered learning approaches.

Samuels and Weir (2002, p293) present this roadmap in the form of an acyclic flow diagram (see figure 1). This approach aims to guide the student through the 'forest of complex choices' and provide strategies for selecting 'the excellent from the merely good' (Ashby, 1999, p2).



(a) Acyclic flow diagram

Figure 1: Design Methodology: Acyclic flow diagram from Samuel & Weir, 2000, p 293

The key concepts addressed in the paper, Design Methodology, are outlined in the following table:

Key Concepts addressed in paper	Selection of elements covered
Understanding Design	Design process overview; questioning and Fermi techniques; resolving conflict
Design process	Evolution and formulation, objective trees, weighted objectives; acyclic versus linear-serial design process diagrams
Managing design process	Scoping, spending, scheduling, function/means trees
	Design space, morphological charts, prototyping, modelling, ethics, environmental aspects

Material selection in design	Function, material, shape and process, limits, indices, standards
Design against Failure	Including risk management, OSH
Case studies	Various including whisker pole, compression spring

Table 2: Key concepts addressed in Design Methodology

Case Studies

Case studies are used throughout the paper. The range of case studies has been selected to make the applied learning of design methodology authentic (Boykiw, 2002). Case studies are not 'student initiated' however, they have been designed to challenge students to learn new concepts and not just apply knowledge already learned (Hendy & Hadgraft, 2002). In initial case studies there is a need to demonstrate the joining of theory to practice and guide students to explore other aspects of the design context (eg ethics, financial considerations, personal and professional judgement, the effect of time constraints). As the paper progresses through these case studies, autonomy in learning and the tools of the design process are progressively handed over to the student.

A typical case study in the materials selection area involves the selection of an appropriate material for a whisker pole as used on an Americas Cup yacht (ref Appendix 1). This particular case study is fairly structured with instruction in related design theory (ie columns) included in the study. The relatively new approach to material selection (Ashby, 1999) making use of design optimizing parameters or material indices is also included and enables students with limited detail knowledge of material properties and behaviour to gain an understanding of the basic material selection process. The approach offered by Ashby (ibid) seeks to establish a performance index for any given application which will allow the selection of an appropriate material based on material selection charts. These plot various material attributes against each other, and material indices plot as contours on these. In Appendix 3 a summary of the material selection process and a typical selection chart are included.

A later case study requires the design of a compression spring in a pressure relief valve (ref Appendix 2). By the time students reach this case study it is anticipated they have the skills and abilities to determine both process and detail design outcomes relating to the design of the compression spring. Therefore, the case study while referring students to a selection of appropriate design texts and data relating to the design, adopts a completely student centred research/learning process with little 'teaching' intervention, although the lecturer is still available in a consultative role.

Student feedback

The design methodology paper was offered for the first time in 2002, and was generally well received by students. Student evaluation of the paper showed that 100% considered that it stimulated ongoing learning. 86% were satisfied with the interest and challenge generated, and confirmed the usefulness of resource materials (textbooks, handouts, paper guides, etc). This and other student feedback indicates little module modification is necessary at this time from a learner perspective. However, a more inclusive overall analysis of project work versus formal assessment (Mills, 2002) would give a better picture of need for change, by using year to year / module to module comparisons. Proposals for modification would then be submitted to the programme Board of Studies for approval.

Discussion

Teaching design is both problematic and essential. The approach identified above responds to the following:

- The essential nature of design as a core capability of the engineer,
- The requirements of design for accreditation of an engineering degree
- The locus of design as a place of integration of theory and practice in engineering
- The 'real-world' context for teaching and learning 'authentic' engineering
- The 'real-world' context for the initial formation of graduate attributes and capabilities
- The importance of teaching methods accommodating a range of learning styles.

We have attempted to define, given the constraints of time and space within an already overfull curriculum and 'non-traditional' graduate profile, a way of balancing: firstly, the need for design; and secondly, questions relating to 'what form?' does design take for this engineer. It will be apparent that the curriculum and this paper specifically address the need for a fundamental grounding in the principles of design methodology. Our difficulty is in finding space for the iterative cycles of design which are essential in design for manufacturing/production contexts. While the Department of Mechanical Engineering at AUT is experienced in teaching design, the approach outlined in this paper is relatively new, and your feedback and advice based on your own learning in developing curriculum for 'new' and 'hybrid' disciplines of engineering is welcome. Given the ever changing context of engineering education, the challenge of maximising design environments to deliver significant learning experiences in, and as close as we can approximate, 'real-world' engineering in our classrooms will continue.

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Appendix 1

DESIGN METHODOLOGY
Project B MATERIAL FOR WHISKER POLE

Problem Statement

Racing yacht designer Tamberlain designs an Americas Cup boat. When using a spinnaker, the spinnaker pole is held in place and can be adjusted fore (forward) and aft (backward) with a brace (high strength rope), which leads from the outer end of the pole, back to a winch at the stern (rear) of the yacht. Two other ropes control the height of the pole, which has its inner end attached to a slide on the mast. Spinnakers are the large colourful sails used for off the wind sailing. ie. the wind is coming from the beam (side) or aft (rear) of the yacht.

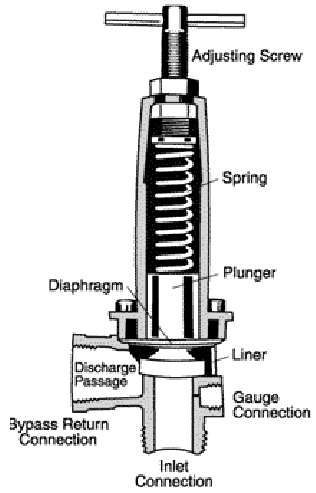
When the wind moves forward of the beam, the pole is eased forward to provide the right angle of attack for the sail and to keep it filling and driving the yacht forward. In order to prevent the pole hitting the forestay (wire rigging from mast to bow), and to give the brace a more favourable angle to the spinnaker pole, a second pole known as a whisker pole is used. This is much shorter than the spinnaker pole. It is also attached to the mast at its inner end, and juts out at right angles to the boat, with the brace passing through its outer end. It is not supported in any other way and its ends can be considered as pinned. The pole is to be of minimum mass, and must support the compressive loading imposed by the brace without buckling. Ideally it should have as small a cross section as possible. It must be able to withstand knocks and bumps imposed during use. Cost should also be considered, even though this is for a large budget campaign.

Determine suitable material indices and select candidate materials which will satisfy the above requirements. Justify your choice(s).

Appendix 2

DESIGN METHODOLOGY
Project E HELICAL SPRING FOR PRESSURE RELIEF VALVE

<u>Problem Statement</u>
A helical spring with squared and ground ends is to be used in an adjustable pressure relief valve. Operational and dimensional criteria determine that the spring must exert a force of 270 N at a length not exceeding 62.5 mm and 470 N at a length of 50 mm.
The spring must fit within a tube of 37.5 mm inside diameter, and the loading can be assumed to be essentially static (ie. the valve is only expected to operate in an emergency).
Determine a satisfactory design, specifying wire diameter d, coil; diameter D, and number of coils, N. The material for the spring will be ASTM 229 wire without presetting.



1. Assume a clash allowance of 10% (ie. spring will have an allowance of 0.1D between maximum load condition and chock or solid condition).
2. There are no unfavourable residual stresses in the material.
3. Both end plates are in contact with nearly a full turn of wire.
4. The end plate loads coincide with the spring axis.

Appendix 3

DESIGN METHODOLOGY

Basics of Material Selection (Ref Ashby Ch 5)

Material selection in design demands profile of material attributes. Ashby likens the process to that of hiring a new staff member.

1. Develop profile
2. Apply property limits
3. Develop material index by considering combination of attributes
4. Make choice

Deriving Property limits and Material Indices

The main considerations are:

1. Function: What it must do? -support load, insulate against cold.
2. Objective: To optimise performance -cheap and as strong as possible.
3. Constraint: It must achieve -cost < \$100/kg, deflection < 1/500 span.

Component must achieve objectives whilst still meeting constraints.

Performance

Performance P dependant on

1. satisfying functional requirement F
2. the geometric parameters G
3. the material properties M

This can be stated as: $P = f[F, G, M]$

or: $P = f_1(F)f_2(G)f_3(M)$

Maximise performance by maximising $f_3(M)$

where M is known as the **Material Efficiency Coefficient** or **Material Index**

Case Study

For the whisker pole case study where minimum mass m is the required objective,

$$m = \left(\frac{4P_C}{n^2\pi}\right)^{1/2}\left(L^2\right)\left(\frac{\rho}{E^{1/2}}\right)$$

Given a specified length L, and load P_C, minimising mass requires maximising the material properties term. Our material index thus becomes

$$M = \left(\frac{E^{1/2}}{\rho}\right)$$

where E is the elastic modulus and ρ is the density. As can be seen from the following chart, materials are naturally grouped within contours, or envelopes of performance. Materials which lie along a particular $\left(\frac{E}{\rho}\right)^{1/2}$ gradient line perform equally well. Materials above the line perform better, those which fall below the line do worse.

Choosing a particular gradient provides a search area, which can be further narrowed by adding property limits.

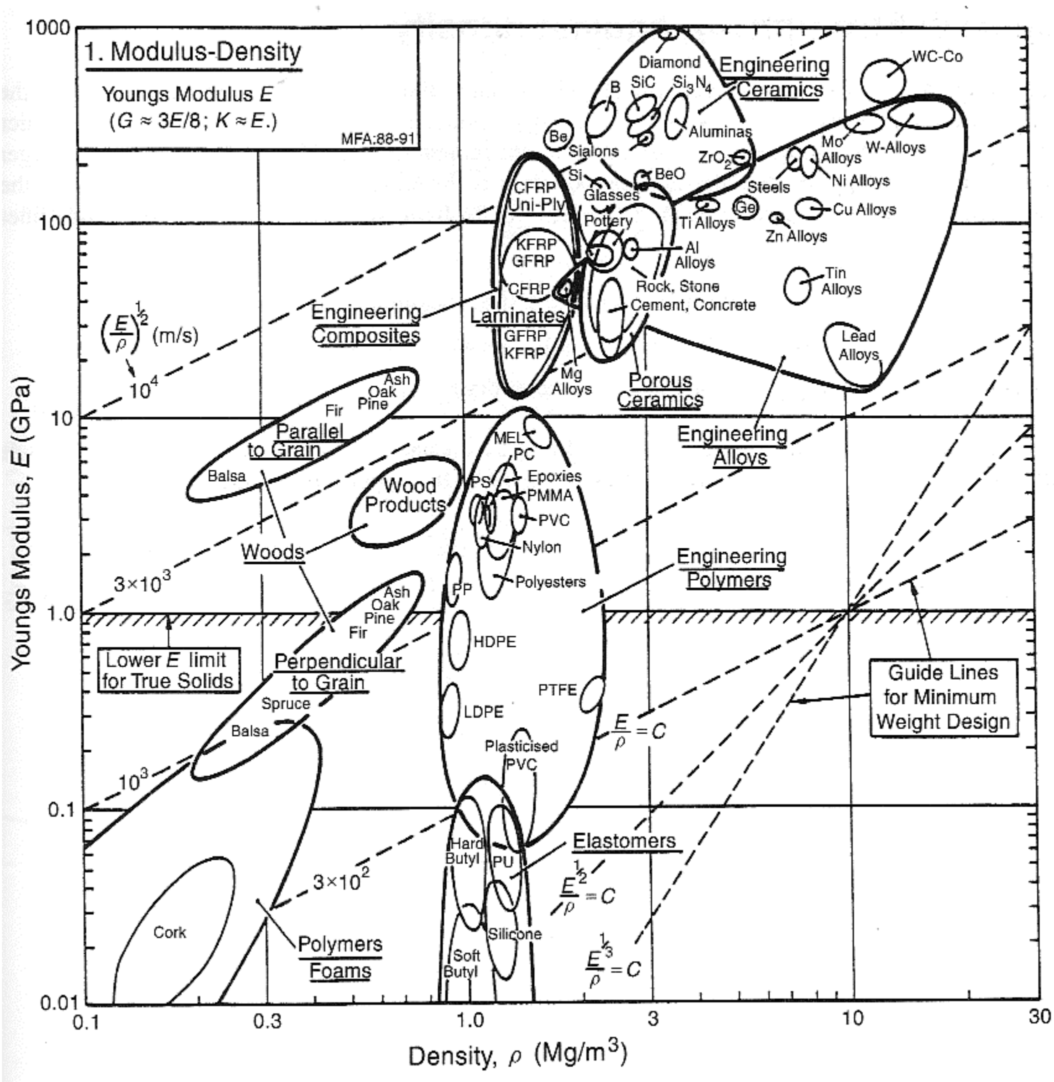


Chart 1: Design Methodology: Young' Modulus, E against density, *ρ* from Ashby, 1999, p419