Stranded Structural Analysis and Design: An Alternative Teaching Approach

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Abstract: This paper describes an approach to teaching fundamental structural analysis principles by linking them to the conceptual design of a structure. Desired graduate competencies were evaluated by market place civil engineering professionals from surveys which assess current subject content. Survey results reinforce the premise that stranded course structures (in contrast to traditional layered course structures) provide the outcome orientation required to promote deep learning in line with the primary recommendation emerging from the 1996 Review of Engineering Education. Furthermore, the inclusion of more problem-based and project-based design subjects is likely to increase the experiential competency of our future graduates and provide a better return on investment for their employers.

Keywords: stranded course structures, course design.

Introduction

The engineering profession is calling for graduate engineers to have a broader education that is directly linked to the practice of engineering design.

Design is the dominant activity that distinguishes engineering from the basic sciences, because the engineer's central role is to create artifacts (Simon, 1981). This view is echoed by Kartam (1998) who argues that *"the heart of engineering education is to develop the ability to design: to engineer is to design."*

Despite the importance of design, there is increasing dissatisfaction within the engineering profession concerning the ability of graduate engineers to solve open-ended problems and produce quality design work (McMasters and Ford, 1990; Nicolai, 1998).

The review of engineering education in Australia (IEAust, 1996) and research by Doherty et. al. (1996) has confirmed that the layered structure of engineering undergraduate courses focuses on science-based learning, complex analysis techniques and detailed design closed-form problem solving; at the expense of conceptual design methodology. Professor Peter Johnson (1996) states that we need to *"change the nature of engineering courses, to provide graduates with a better understanding of the broad human, economic and environmental consequences of professional tasks"*.

Consequently, it is of paramount importance for curriculum designers to canvass professional engineering employers for program revision guidance. This process is an integral part of a 'training needs analysis'. Desired graduate competencies were evaluated by market place civil engineering professionals from a survey which assessed current subject content. The next logical step was to incorporate the results of such a survey into the design of engineering subjects.

This process has begun for two diverse subjects taught at different Australian universities. One first year subject is concerned with teaching fundamental structural analysis concepts. Rather than consisting of isolated 'mechanics' topics, the subject has been re-organised so that students directly apply structural analysis to design problems as they learn about them in order to understand and respect the relevance of the analysis techniques. The second final year subject is a large-scale integrated design subject that requires students to work in groups to produce viable conceptual design and detailed design reports for a major bridge project.

Survey Development

The field of civil engineering endeavour is so broad that what may be vital to one engineer and relevant to his or her work history may well be irrelevant to another employed in a different field. How then does one compare what may well be unique work history and personal viewpoints to the wider collective opinion? The results need to be more than individualised opinion while also needing to be statistically compared.

Approximately 155 survey questionnaires (Lemass 2004) were sent out to professional engineers via the very cooperative Alumni Association and the Director Marketing, Recruitment and External Relations at the University of Wollongong. A mail out package was prepared by one of the authors which included a cover letter and an introductory comment from the Alumni Association, a stamped self addressed envelope and the questionnaire.

The first few versions of the survey consisted of mock interviews to establish a set of questions that encompassed the wider range of possible responses. Presenting these questions in tabulated form permitted each interviewee to provide a written response based on his or her experience. This gave rise to a rather lengthy questionnaire which was considered to be undesirable. However, permitting responses to be made by ticking the appropriate box rather than requesting written feedback kept the interview duration down to an acceptable time allocation of approximately 20 minutes. If the interviewee felt that additional written clarification was required this was encouraged.

The finalised questionnaire was designed to gather data in the target areas noted below. Only the bachelor degree assessment results will be discussed in this paper.

- Bachelor Degree in Civil Engineering- Course Content Assessment.
- Desired Experiential Skills for Civil Engineering Graduates.

Completed questionnaires were received for analysis from 40 professional engineers within the structural, geotechnical, water and management specialisations of civil engineering. Based on their own work experience, current subject topics were rated in terms of civil engineering relevance.

Survey respondents rated subject topics (extracted from the University Undergraduate Calendar) from *irrelevant* through to *vital*, with assigned evaluation score limits being 1 and 6, respectively. Questionnaires did not differentiate between 'core' and 'elective' subjects in order to minimise any biasing potential from survey respondents.

Survey Results

Results have been presented in two formats. Firstly, analysed survey data were collated in tabular format showing all listed subject topics, with the rating of usefulness in the adjacent columns. An extract from the full table is presented as Table 1. Secondly, subject topic grading means were plotted in a graphical format with one standard deviation shown each side of the mean to indicate that 95% of results fell within this range (extract shown as Figure 1). Subject topic names were removed for graphing purposes and were replaced by numbers ranging from 1 to 157 (extract shown as Table 2).

Topics and associated Subjects	Relevance of each subject to interviewees' current position & associated work history leading thereto					
	irrelevant	very limited use	limited use	useful	very useful	vital
Fluid properties				▲		
Hydrostatics				▲		
Manometry			▲			
Bernoulli's			▲			
Mass energy and momentum EQ's.			▲			
Dimensional analysis			▲			
Fluid flow in pipes				▲		
Electrical circuits			▲			
Electrical measurements			▲			
Instrumentation			▲			
Data logging			▲			
Heavy current devices		▲				
Engineering design and philosophy				▲		
Engineers' role in modern society				▲		
Communications processes					▲	
Research methods				▲		
Oral and written communication techniques						▲

Table 1: Course Grading Questionnaire Results – BE Civil – Combined Specialisations Extract

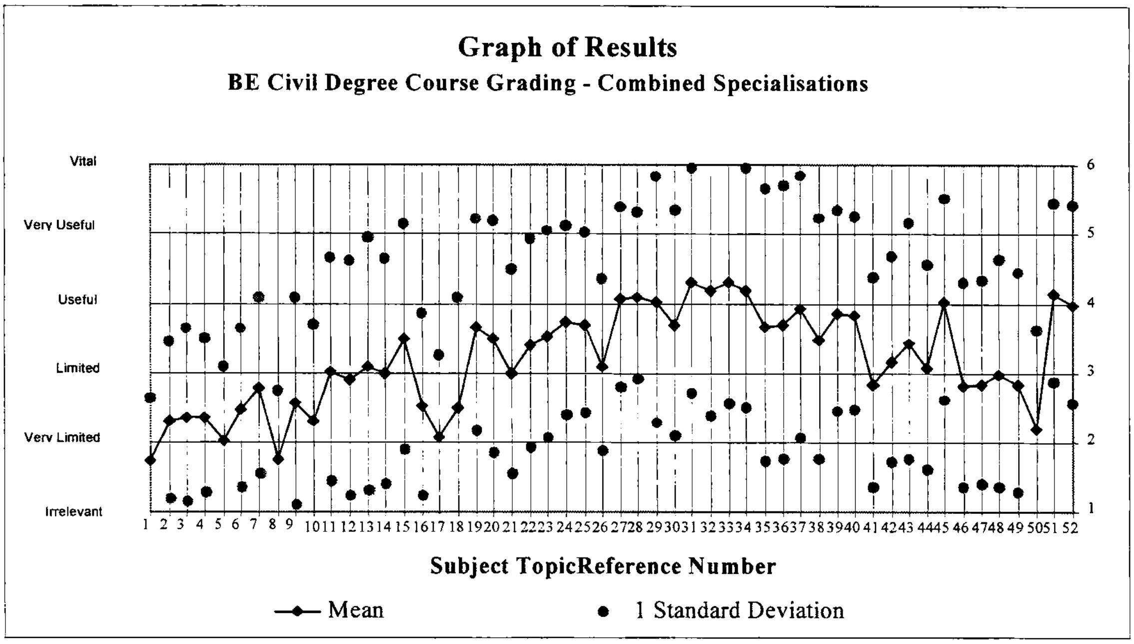

Figure 1 : Graph of BE Civil Degree Course Grading – Combined Specialisations Extract

List of Subject Topic Reference Numbers		
Chemistry	Atomic theory	1
	Chemical bonding	2
	Structure	3
	Molecules and reactivity	4
	Thermodynamics and thermochemistry	5
	Gases, liquids and solutions	6
	Chemical basis of engineering materials	7
	Kinetics and radiation chemistry	8
Mathematics 1	Matrix algebra	9
	Determinants	10
	Vectors	11
	Differential and integral calculus	12
Mathematics 2	Calculus	13
	Differential equations	14
	Numerical maths	15
	Sequences and series of numbers	16
	Complex numbers	17
Mathematics 3	Differential equations - laplace transforms, Fourier series, and special functions	18
	Statistics	19
Engineering Mechanics	Two dimensional statics of particles and rigid bodies	20
	Kinematics of particles in rectilinear and plane motion	21
	Equations of motion	22
	Work and energy impulse and momentum	23

Table 2 : List of Subject Topic Reference Numbers (Extract)

Discussion of Survey Results

It is important to note that survey results obtained using the approach outlined in this paper are highly dependent on the accuracy of subject topics listed in a University Calendar.

Subject topics that were rated as *very useful* to *vital* by employers of civil engineering graduates include:

Professional Engineers and the Management of Technology

- Communication Processes
- Oral and Written Communication Techniques

Engineering Management

- Financial Management of Engineering Projects
- Quality Management
- Statistical quality management tools
- Contracts and Contract Management

Project Management and Human Factors in Engineering

- Project Management
- Total Quality Management
- Human Relations
- Accident and Risk
- Industrial Relations Occupational health and Safety

Computing one

- Windows
- Excel

Structures three

- Finite element analysis

Construction

- Plant and Equipment

Civil Engineering Design

- Integrated project: geotechnical, hydraulic, structural and transport

Survey results reinforce both the importance of management subjects and arguments from Doherty et. al. (1996) and Warner (1989) for engineering curricula to be re-designed away from traditional *layered* structures towards *stranded* structures.

In layered courses, attention is initially focused on science and mathematics, followed by engineering analysis and detailed design (Figure 2(a)). Conceptual design methodology is only introduced towards the end of the four-year undergraduate program.

In stranded courses, students are exposed to open-ended design problems at the start of an engineering degree (Figure 2(b)). In this manner, both analytic and creative thinking skills evolve over four years, while science and mathematics are interlinked for problem solving only when they are needed in engineering applications; thus overcoming student motivation problems.

A similar survey of graduates and employers conducted by University of Sydney (Airey et al., 2005) found that: "*...many graduates and employers expressed a desire for a more practical* *focus to the course, with greater involvement with the practice of engineering".* Focus groups of civil engineering students at the same institution "*...particularly in the early years, did not see much connection between what they were learning and engineering practice and thought that this should be a priority for any change".*

Of course the problem is not just an Australian phenomenon. Froyd et al (2005) at Texas A & M University record that *"students often fail to grasp the nature of how their courses are connected with engineering practice".*

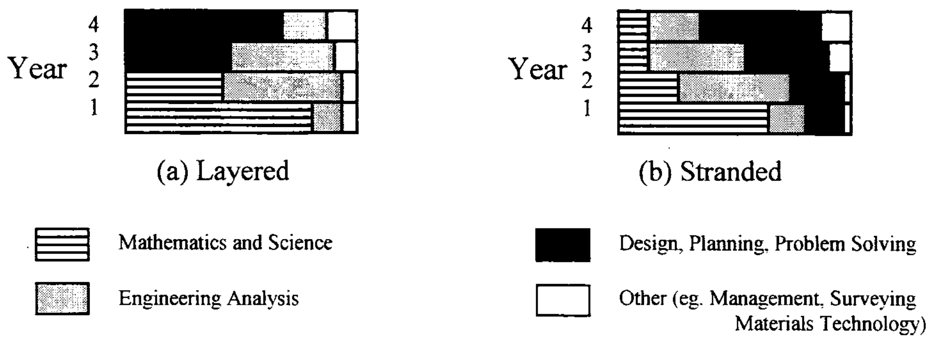

Figure 2: Civil Engineering Course Structures (Adapted from Doherty et. al., 1996)

Development of 'stranded' design/analysis subjects

In view of all of the above the authors set about changing the configuration of a fundamental structural analysis subject to reflect the surveyed priorities of practising engineers.

Today, in many universities worldwide, structural analysis and design continue to be taught in two disparate streams. In reality, structural analysis methods have been developed *in response* to the *design needs* of the community. It is therefore important to recognise that structural analysis is an integral component of the structural design process; and not the other way around.

However, complex manual analysis techniques and tedious iterations often taught as 'design' at undergraduate level have discouraged many student engineers from wishing to pursue design careers. Engineering design and analysis need to be modelled, integrated and taught so that they can be perceived as being less formidable, less mathematically intensive, more relevant to real world applications and hence more desirable as a career prospect. Dr. John Roberts (2004) aptly states that *"what is needed is a constant reminder that analysis leads to design, and marrying these two every step of the way brings structures teaching and study to life."*

It therefore seems much more logical to introduce structural analysis concepts *gradually* in engineering design education. One way of doing this is to link fundamental structural analysis concepts to the design of a major structure and to learn these concepts only when we *need* to know about them. It is also important for engineering students to gain some insight into the limit state approach to design practiced around the world at the *same time* as they are grappling with analysis procedures (Lemass and Gardner, 2005).

Various engineering education institutions in Australia have a final year subject that aims to integrate skills and knowledge from diverse subject areas into a cohesive design process for a civil engineering project eg. Integrated Design Project at Griffith University, Computer Modelling and Design at University of Technology, Sydney, and Design Week at the University of Melbourne. The authors believe that students will be able to see the "...relevance and interrelatedness" (Chowdhury et al, 2005) of what they're learning if the instructional approach of design is used from the very beginning of their engineering education.

In this stranded first year subject the design scenario is introduced at the beginning of the semester. Students are to complete a conceptual design of a 'sister' bridge to the existing truss bridge over the Clyde River at Bateman's Bay (Figure 3), using current design loads and rolled steel sections. The introduction of the scenario means that students are immediately working in context. Truss bridges are progressively being duplicated up and down the coast eg. Tom Ugly's Bridge at Sylvania in Sydney, and the bridge over the Shoalhaven River at Nowra. The philosophy of limit state design is also introduced at an early stage as part of the framework for the concept design.

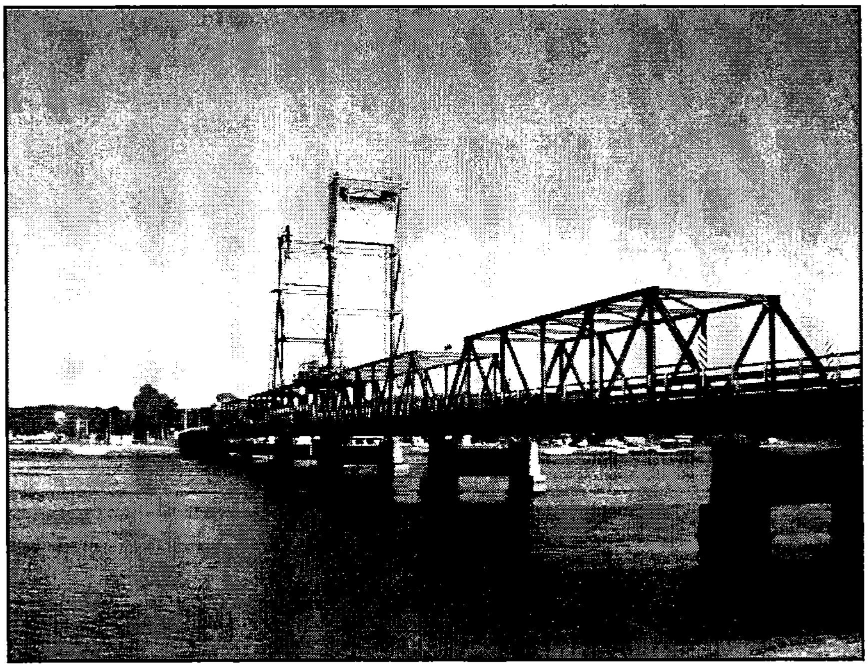

Figure 3: The Existing Bateman's Bay Bridge.

Having students complete a conceptual design provides an opportunity to discuss what is meant by that term and to 'brainstorm' other solutions to the problem of carrying traffic from one side of the river to the other.

Using the bridge the students are introduced to load types and load paths, to classifying supports and calculating reactions. After tracing the load path of the bridge students are encouraged to look for the load paths in all the structures they can see around them.

In designing members for axial loads the students become familiar with both method of sections and method of joints analysis of trusses, with calculating axial stress and strain and the deflection of struts and ties. By applying these concepts to the design of the bridge truss students can immediately see why they need to learn this material. A typical assessment task at this stage is to size truss members for an alternate truss design. Students choose the existing Pratt truss configuration or a Howe or Warren truss configuration, analyse their chosen truss for member actions, and then use an elementary application of strength limit state analysis to decide on member sizes choosing UCs, UBs, CHSs, RHSs, or SHSs throughout. The debriefing session from this assessment task includes the compilation of a table showing the weight of the various truss configuration and member shape combinations. This process illustrates how engineers use analysis for concept design decisions, and, if nothing else, shows why engineers don't need to express their result to six decimal places for every calculation they perform.

Once the trusses have been designed students can progress to designing members for shear and bending. This involves defining shear force and bending moment, and the relationships between them, as well as drawing appropriate shear force and bending moment diagrams. Using the values from this analysis, along with relevant geometric properties of the sections (eg. second moment of area) allows students to evaluate bending stresses in the cross girders and stringers of the bridge and so come to some preliminary sizes for these members.

As well as strength of course, engineers consider serviceability of a structure, and this is included with some consideration of the deflection of the cross girders and stringers on the bridge. This provides an opportunity to consider the interplay between strength and serviceability design.

Further development includes closely linking assessment tasks to the design and analysis processes introduced in the concept design of the bridge and prompting students to generalise these to other structures.

Student reaction

Students appreciate being able to apply their fundamental skills to real structures. They begin to recognize the importance and relevance of the subject material to them as potential practitioners of civil engineering, rather than as simply students moving through an academic course of study. One student commented after the completion of the subject: "The skills that I have learned to adapt from this project are still useful for me everyday while doing my work experience out on site"(Mikhail 2005).

Other student surveys have returned comments such as: "I particularly like the fact that you could relate the problems to real life scenarios…", " That it's 'real' engineering, it teaches you how to look at structures so that you can design them…", "…it was a very industry related subject that I enjoyed", " I liked the practical aspects and what we learnt could be applied to the real world", "…relevance to professional practice".

Alignment with current trends in teaching and learning

The proliferation of instructional approaches such as project-based and problem-based learning, case study methods and competency-based learning has resulted from recognition that authentic learning tasks can motivate students to engage with the material. However, Merrienboer et al. (2003) warn of the risk, inherent in all these approaches, that learners

"…have difficulties learning because they are overwhelmed by the task complexity". To avoid this, the authors have used various methods which correlate with those suggested by researchers in cognitive load theory.

The design of a bridge is a complex task. However, by operating at concept design level learners can develop a framework to organise the various elements of further learning at detailed design level, and to help understand how these element interact. This is apart from developing and practicing skills in concept design which is itself valuable learning for civil engineers. So the relatively simple but still authentic 'whole task' allows learners to co-ordinate and integrate simple but powerful design skills from the beginning of their education and progress to more complex versions as they advance through their course.

Cognitive load researchers (Merrienboer et al, 2003; Van Lehn, 1996; Paas et al., 2003) advocate the use of worked out examples so that the learner can focus on understanding generalisations and hence creating schemas. A schema is an ordered combination of multiple elements of knowledge need to solve a problem or perform a task. Once a schema is constructed it can be brought from long term memory into working member and operated as a single element, rather than as a series of elements. Merrienboer et al. (2003) suggest that to construct these schemas information should be "…presented precisely when learners need it".

One of the differences between experts and novices is that experts have a greater number of schemas to access and can process many of them automatically, as opposed to the step-by-step process of the novice. Merrienboer et al (2003) recognise that the 'whole task' learning process may not provide enough practice to develop this automation and suggest that additional 'part-task' practice may be provided. However they stress that this practice should only take place once learners have had an opportunity to understand where these tasks fit into the whole. This correlates with the introduction of new material in the context of the bridge design and progression onto 'end of topic' discussion and competency exercises to increase speed and accuracy of such processes as finding reactions and drawing shear force and bending moment diagrams.

Conclusions

In order for our future graduates to 'hit the ground running' and provide a better return on investment for their employers, curriculum reviewers need to obtain (and act on) feedback from the market place: *"…the 'learning-by-design' approach to statics … helps prepare students for the job market….*"(Chang & Fourney 2000)

This paper has outlined a market research approach that has yielded important output for aligning tertiary education curricula with the expectations of the civil engineering profession. The output from this survey inspired a change of approach to the teaching of fundamental structural analysis which highlighted the design applications of the material covered. This new approach aligns with current developments in designing instructional material to help learners learn

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Proceedings of the 17th Annual Conference of the Australasian Association for Engineering Education

All papers accepted for publication in the Proceedings of the 17th Annual Conference of the Australasian Association for Engineering Education were submitted as full papers and peer reviewed by at least two members of an expert editorial panel. Based on these reviews, authors were asked to revise their papers before a final decision to accept and publish the paper was made. This process of reviewing is in accord with the criteria set by the Department of Education, Science and Training (DEST) of the Australian Government for published papers.

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Introduction and Welcome:

On behalf of AUT University, welcome to the 17th Annual Conference of the Australasian Association for Engineering Education (AAEE) and the 11th Women in Engineering Forum.

The central theme for this year's AAEE conference is:

Creativity, Challenge, Change: Partnerships in Engineering Education.

Creativity, challenge and change create the context in which contemporary engineering exists. This dynamic environment is evident in our partnerships with students, teachers, researchers, industry, government and society. At this international forum we explore the ways these partnerships are responding and working towards successful outcomes for all stakeholders in this context. The conference aims to identify and promote best practice in engineering education partnerships within this creative, challenging and changing environment.

The conference program focuses on partnerships between:

- Learning and teaching
- Teaching – research nexus
- Sustainability and interdisciplinary partnerships
- e-learning and engineering education
- Engineering and society
- Maori and engineering
- Professional bodies and education
- Government funding and institutions
- Local and international engineering education providers
- Industry and education.

An additional focus in the event this year is the special focus on industry/stakeholder needs through a full panel session with industry leaders.

The quality of papers this year has been very high and well aligned to the core themes and I would like to thank the paper sub-committee headed by Dr. Gerard Rowe and all national / international referees for their valuable contributions.

I would also like to thank the Organising Committee and Conference Secretariat for their hard work, excellent advice, and passion in Engineering Education and into making this event a success. It has been a pleasure chairing a team of such creative professionals.

The conference promises memorable events and we hope that you will enjoy them while visiting AUT and New Zealand.

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