A TOP DOWN APPROACH TO TEACHING ENGINEERING MECHANICS

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ABSTRACT
The teaching and learning of finite element analysis has to date been reserved for final year undergraduate or masters level engineering students. The assumption behind this is the considerable mathematical content associated with this method demands much pre-requisite knowledge and conceptual understanding. The module which is the focus of this study challenges these beliefs by introducing finite element analysis to second year design technology students, who have minimal experience in mathematics and mechanics. The project based delivery of this module looks to primarily address the conceptual issues surrounding mechanics of solids and finite element analysis, and secondarily the theoretical and mathematical issues which underpin mechanics. This study discusses relevant literature on teaching methods for finite element analysis and mechanics of solids modules, and includes a reflection upon the first year of this module at the University of Brighton, with constructive feedback from students and staff. There were considerable overlaps between these perspectives, including the potentially key role of software in the learning process, the need for a hands-on problem solving approach, and the need for clearly defined course objectives, material and references.

INTRODUCTION
A traditional engineering curriculum is understood to be lecture based complemented by tutorial, practical and laboratory work [1]. It is commonly presented in a modular format; individual subject-based modules taught are often isolated and independent from one another, with one major project at the end of the degree. This approach is reflected also in traditional engineering reference material. This study looks to create an integrated top-down approach to teaching engineering content, with students carrying out an engineering design project that integrates relevant engineering skills, techniques and tools. One such tool is finite element analysis which can be used to assist with the conceptual understanding of general mechanics and applying this to improve engineering design.

FINITE ELEMENT ANALYSIS
Finite element analysis can be used in mechanics (among other engineering areas) to analyse stress, strain and deformation throughout the particular structure. Essentially it is a numerical technique to solve a series of simultaneous equations that break down a complex problem into a series of smaller, simpler problems solved collectively. Considerable processing power is required, which in recent years has become available on standalone personal computers, making finite element analysis a mainstream design tool [2].

With appropriate model development, finite element analysis can be utilised on a number of levels in the mechanical design process. These include but are not limited to:

- A means to seek out potential weak points in a design, so that the design can be iteratively improved through feedback
- A means to investigate whether or not a structure will yield or even fail
- A means to investigate the behaviour or sensitivity of a structure through changes in one or more design parameter (e.g. dimension or material property)
- A means to optimise the design of the structure by iteration and feedback of the above.

Such a versatile and useful tool should at least be available to designers, and not just engineers and physicists. With relatively intuitive user-friendly software developed, designers should, with appropriate education, be using this software to support the design process.

TEACHING METHODS IN MECHANICS AND FINITE ELEMENT ANALYSIS

The use of computer aided engineering including finite element analysis can help overcome the barrier of fragmented learning and improve the overall learning experience of engineering and technology students [1]. A typical finite element analysis taught engineering module, like other engineering subjects would be delivered as a series of lectures, tutorials and practicals, and would be assessed as a written examination and possibly coursework. The underlying integral calculus and numerical techniques are often at the forefront of the learning outcomes, with little emphasis on the conceptual understanding of the problems when applied in a practical context. The students' conceptual framework is not typically an outcome of traditional teaching methods [3]. The relevance of the topic to applied situations can be unclear even upon completion of the module.

One of the barriers separating designers from finite element analysis is the way in which it is presented and taught. Few of the reference books available on this subject are able to present finite element analysis in a light that is understandable to those who are not numerically proficient. Only recently have texts and training manuals begun to address the conceptual understanding of the reader when trying to introduce finite element analysis in a practical environment [4-6]. Even they are focused on the numerical formulation of the method and the accompanying theory rather than balancing this with conceptual understanding and application in design. We do need numerate students to learn theory to develop this software for research and development; we also need students to learn and practise the application of this software in engineering design and product development. It has been argued that finite element analysis could also be included as a teaching tool in low level mechanics of solids to aid the conceptual understanding of these topics through visualisation and demonstration in order to complement the theory [2].

In fact, the subject-based approach, requiring students to solve standard 'end of chapter' or exam problems, which tends to dominate teaching methods currently used in engineering and physics, can be a poor method of testing and teaching for functional understanding [7]. In engineering mechanics, "acquiring a conceptual understanding has proven to be one of the most difficult challenges faced by students" [7]. So what other methods could be used?

One method used by Bernhard was to firstly introduce all new concepts by a Microcomputer-based laboratory (MBL) demonstration in a lesson, then apply them in solving problems [7]. Emphasis was placed on "thinking aloud" about the concepts, context and the relevance of the answer, modelling professional practice.

Jolley *et al* present an undergraduate module on finite element and theory and practice, which consists of an integrative project and homework exercises [8]. This project based module aims to support the teaching of the finite element method and to "emphasise assumptions and limitations in the application of the technique". These authors also highlight that conceptual mistakes are often made by students and at times by practitioners when using commercial software. Feedback and discussion on this conceptual interpretation is crucial for development on this level.

Yet another relevant approach to teaching finite element analysis was presented by Jensen and Pramono, which looks at using both commercially available software (MSC/Patran) and software developed in-house by faculty staff [9]. The complexity and extension advantages of using commercially available software has the down-side that it will prevent sudents from writing portions of the finite element code, which "for many students … may be the single best learning tool-available"

A TOP DOWN APPROACH TO TEACHING MECHANICS OF SOLIDS

This section looks to reflect upon the module which is the focus of this study (as delivered in 2005-06 & 2006-07), from both the teacher's and students' points of view. It introduces the results from two questionnaires, one for students on this module and another for staff in the engineering and design areas. The student questionnaire included a comparison with other experiences, critical evaluation, influence on conceptual understanding and some suggestions for the future. The staff questionnaire, aimed at design teachers and engineering teachers, as well as those who straddle the domains, seeks to gauge current teaching methods and past experiences, as well as feedback on this module and suggestions for the future. Useful insights will be summarised at the end of this section in order to implement ways forward in the following section.

This 20 CATS module has been running for two academic years, each spanning 29 weeks, including 26 weeks of delivery and 3 of revision and assessment. Three hours per week were split evenly between the electronics component, and the mechanical component (the focus of this study). The students were B.Sc. students in design and technology, with little engineering maths experience.

The learning outcome related to this part of the module was to 'optimise complex component geometries within designed artefacts'. A summary of the module structure, which was broken down to 4 key stages in the project, is as follows:

- Mechanics of solids
- Introduction to finite element analysis
- Using software to carry out a finite element analysis
- Optimisation using finite element analysis

The delivery and assessment for this part of the module was project based with focus on interaction and engagement of staff with small student groups to enhance their problem solving ability and conceptual understanding [7, 10]. The module involved the complete re-design, analysis and optimisation of a lift mount. At the beginning of the module, students were shown an existing staff generated design. Each student group (2 or 3 members) then created a plan for their project to be worked through in class. Classes involved a small introduction to the section with some relevant examples followed by students working on their project with support from staff. Students had access to materials and fabrication workshops in order to build their prototypes. A typical plan for students would include detailed design, testing, evaluation and iteration stages:

Several summative assessment stages were required of students, including:

- An interim group report, outlining the design, analysis and experimental work (week 13)
- A final group report, (final design, design process, analysis and optimisation) (week 28)
- A presentation of the final group designs, to see it working and in context (week 28)
- A viva-voce for individuals on the report and their conceptual understanding (week 29)

Reflecting back on this module, it seems that the first attempt to deliver this type of content to undergraduate design students was a positive experience for both staff and students. Student engagement, commitment and attendance levels (mean 92% attendance) were generally very high throughout the year.

Students used the commercial software appropriately to optimise design, compare predicted output with test results based on measured material properties and discus the relevance of the methodology.

STUDENT FEEDBACK

Student feedback on this module, the teaching and learning methods associated with it, and the support given by staff, was overall very positive. There were however, some very useful insights and comments which should be taken into account for the preparation and delivery of this module next year.

Students seemed to respond well to being shown how to do the task first. One student commented: "I personally like a simple step by step walk through done by the teacher, where I can follow on my computer and make notes". The use of software to demonstrate mechanics was also found to encourage student learning: "I found it easier practicing with the program than using worksheets". Another student commented: "a positive aspect of this module was discovering aspects of engineering that I would otherwise struggle to deal with; discovering them in a way I enjoy, i.e. project and computer application".

Students were also positive when commenting on the use of practical project work to develop their own skills and knowledge: "the fact that it is practical is better as we are constantly applying and testing the theory we are learning". Another benefit of the project based approach, seemed to be the dialogue and discussions that resulted from interactive sessions: "this module is very laid back, which is good in helping me learn!"

When asked how they would rate their confidence with understanding real working mechanical problems after completing this module, students again responded in a positive way: "we used what we had learnt in this module to design a recumbent bicycle and ensure the parts and frame would be strong enough. I feel more confident now". One student also commented on the approach: "this module has taught me how to approach engineering problems from a more logical perspective".

In response to whether they have found out anything about themselves and their understanding of engineering principles in the module, a student suggested "slightly better conceptual understanding…no clue on maths". Another student said "I want to do engineering now, not product design". This suggests that the engineering content was presented in an engaging way for the students and even though some students felt that their ability to do carry out complex mathematics was inadequate, their conceptual understanding was improving.

All 10 students surveyed through this questionnaire said that this part of the module was either "quite enjoyable" or "very enjoyable". All of the students surveyed also suggested that this module was "very appropriate" when asked how appropriate they think it is to teach 2nd year Design and Technology students Finite Element Analysis.

STAFF FEEDBACK

Nine staff completed the staff questionnaire, including five design teachers, two engineering teachers, and two teachers of design from an engineering background. All staff had a minimum of 6 years teaching and lecturing experience in their field of expertise, and three of the staff had at least 20 years experience.

The teaching methods described by the design teachers seemed to focus on several key ideals, including: discussion, examples, learning from problems or projects, concepts, doing, and the bigger picture. The engineering staff on the other hand, seemed to concentrate on maximising laboratory experience, minimising lecture time, applying theory, lectures, tutorials. One colleague summed up the teaching methods of both designers and engineers by suggesting "engineering students work in detail then broaden out to see the bigger pictures. Design students start broad then focus on detail". Their comments give us a good insight into why teachers teach the way they do. Issues such as life long learning, real world issues, seeing the bigger picture, and understanding the domain from their own perspective give the impression that as teachers we are doing more than delivering a set of material according to a curriculum. We are striving for students to experience something which will help them in the future in their education, in their working careers and even beyond. In response to the questions related to the focus in this study, staff were again generally positive and constructive. Feedback on current teaching methods in this module, suggested the following which might be transferable to other, similar modules:

- "the teaching and learning methods presented in this module support and encourage independent learning strategies and are valuable for a life-long learning model"
- "investigative approaches encourage motivation and participation, especially if there are some informed choices made by the students"

Suggestions and potential problems or hurdles that were flagged up by staff, include:

- "there is a real danger of exploring finite element teaching by plunging deep into its mathematics in order to show its strengths and limitations….try not to do it at this stage"
- "perhaps start with real world problems and develop these into concepts"
- "students may feel overwhelmed by a lack of underpinning knowledge. Basic requirements should be clearly outlined"
- "relevance to the design process can be a positive driver for students"
- "beware lack of perceived structure. This can be reinforced with clear criteria and staged (formative) assessments"
- "try to engage students in evaluation, with you being a moderator type of assessor perhaps?"
- "be sure to discuss alternatives, and give examples of what happens if you don't use this methodology. Exercising judgement is important"

Overall the experience of this module has been a positive one. Students and staff were constructive in their feedback and discussions surrounding this module, and many of the key issues identified in literature underpin the introduction of this module to the design syllabus at the University of Brighton. There were considerable overlaps between their perspectives, including the potentially key role of software in the learning process, the need for a hands-on problem solving approach, and the need for clearly defined course objectives, material and references. This study has been a good basis for continued development for the next academic year and hopefully in the years to come.

CONCLUSIONS

In engineering mechanics, acquiring a conceptual understanding has proven to be one of the most difficult challenges faced by students. Teaching and learning methods used in engineering mechanics and finite element analysis have traditionally been very theoretical, and reference material mirrors this approach. This work illustrates teaching methods that react to the need for increased conceptual understanding include the use of project and/or problem based learning, and using software appropriately for the cohort. The top-down practical approach focused by a specific project has been shown to be a promising way forward.

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