Teaching Skills for Conceptual Design - A New Approach

TEACHING SKILLS FOR CONCEPTUAL DESIGN- A NEW APPROACH

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Abstract: Engineering is to a large degree about problem solving and communicating solutions to problems effectively. Despite this, most engineering undergraduate programmes focus largely on technical matters with little time devoted to teaching problem solving skills. This paper describes developing, delivering and assessing a novel course designed to equip students to solve open-ended, ill-defined problems. These kinds of problem are not solvable by computer or easily "outsourced" around the world. Hence graduates with skills at solving them will be well-placed to compete in future employment.

Through problem-based and self-led learning the course enabled students to develop expertise at problem definition, option evaluation, engineering communication and conceptual design. To encourage free exchange of ideas and rapid development of design solutions, informal sketching and approximate calculations were emphasised over formal drawings and precise calculations. Use of Excel as means to communicate, as much as to calculate, was highlighted.

The authors recognised that learning through failure is intrinsic to developing problem solving skill so assessment was heavily loaded towards rewarding engagement with the material rather than "correct" solutions. Moreover, early cycles though the design process attracted few marks so that students could build knowledge and ability without fear of being marked down due to poor initial attempts.

Staff found that while many students were initially flummoxed by the unfamiliar, non-prescriptive nature of the course, over time the value and purpose were recognised. End of course student feedback was exceptionally positive with many comments recognising the value of the content and style of the course.

Keywords; conceptual design, problem-solving, classroom based, learning through failure,

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1. INTRODUCTION

Design is fundamental to the profession of civil engineering. Its importance is highlighted by accrediting bodies such as the JBM (2014) which requires that design is a "thread" of all UK degrees. That is, design must be ubiquitous throughout a degree programme rather than appearing in just a few units. Despite this, little direction is given by the JBM about which aspects of design should be taught. The subject is large with everything from specifying bolts to planning infrastructure for entire countries potentially falling under the label of design. Consequently decisions about where the emphasis of teaching should lie must be made due to limited time in curricula. This paper reports on one aspect of how the focus of civil engineering design teaching has developed recently at the University of Edinburgh as a result of the changing economic and technical landscape. All authors were employed at Edinburgh at the time of the work described, the first three as academics and the last as a teaching assistant.

The authors take the view that in future some abilities and knowledge that were previously considered valuable for graduates will become less valuable as routine tasks are increasingly either entirely automated or undertaken in parts of the world with lower wages than expected in the UK (e.g. Bryant, 2006). In terms of design, this will result in much detailed design work, such as final sizing of structural members, no longer being undertaken manually in the UK by graduates. To be competitive, graduates in future will require skills and abilities that are not easily computerized or widely available elsewhere. There is good evidence that these will include ability at conceptual design (Hines 2012) and its associated skills such as handling open-ended problems, rapid option evaluation, informal technical communication, and use of appropriate software. With this in mind the curriculum at Edinburgh has been developed so the emphasis of design teaching has shifted from the more traditional, detailed (and easily automated) aspects to conceptual aspects. Related to these developments in industry are emerging developments in higher education. Massive-open-online-courses (MOOCS), for example, may threaten traditional lecture–based delivery of material (Yuan and Powell, 2013). Therefore there are drivers for universities to move away from teaching that is built around lectures or other techniques easily distributed electronically to methods such as group as social learning that can not be easily delivered remotely.

In response to these shifts, a new course was developed and delivered to second year civil engineering undergraduates in 2013 that focussed on how to approach open-ended, ill-defined problems. The philosophy of this course and the experiences of staff and students in its first year of delivery are discussed in this paper. Related developments in design teaching in year three have been reported elsewhere (Gillie, et al 2014). The work described herein was also heavily influenced by the authors' experience of running "Innovative Learning Week" activities at the University of Edinburgh in 2012 as discussed by Furber *et. al* (2014).

2. COURSE STYLE AND PHILOSOPHY

The course had two aims: to develop students' abilities at solving open-ended problems, which are typical of the early stages of the design process; and to develop students' confidence in using a range of techniques and tools that are helpful for making such decisions.

Neither of these aims would be well-met by traditional lecture delivery. Developing expertise at problem solving, particularly open-ended problem solving, requires freedom to explore, exchange and experiment with ideas, something that is not easy to encourage in a lecture. Therefore classes and teaching were instead structured to encourage learning through communication, social interaction and as a result of failure. A substantial quantity of group work was included so that several minds were generally working collectively on problems. However, the group work was arranged to ensure communication and discussion between as well as within groups so that ideas, successes and failures could be shared among the whole class. This approach reflected the nature of professional design work and also encouraged creativity and free exchange of solutions. Teaching space was deliberately chosen to be flat "project" space rather than a lecture theatre to encourage this type of working. Although brief presentations by teaching staff were given most weeks, the emphasis was firmly on students working collaboratively to solve problems with staff attending primarily as facilitators. This teaching style contrasted strongly with both classic lecture style teaching that is typical of detailed design classes and also traditional group project design classes that tend to pitch one group against another, with little incentive to exchange ideas between groups.

Central to meeting the first aim of developing students' problem solving skills was setting a range of conceptual design problems of the type that civil engineers might expect to meet in practice. In line with an earlier finding that presenting students with several increasingly complex design problem is much more effective than one "big bang" project for developing problem solving skills (Gillie et al. 2014), problems set early in the course were short (as little as 15 minutes) and then of increasing complexity until the final problem took two weeks. This approach has the key advantage of allowing students to learn from early mistakes (for example pursing a low-quality solution too far) while working on short problems and avoid them in later more time-consuming problems. As the course was focused on developing ability at solving open-ended problems, all the problems (see section 3) were designed to present an engineering need and then to invite solutions to this need. In contrast to more traditional design courses, care was taken not to place restrictions on the form of the expected solution to problems.

Conceptual design requires tasks such as problem definition, identifying and balancing many conflicting requirements, and rapid evaluation of varied options, all of which require judgments based on engineering knowledge. Developing students' expertise at making such judgments is a key part of conceptual design education and requires practice (hence the multiple design cycles highlighted above used in this course) and also reflection on the success or otherwise of previous decisions. To give some structure to students thinking, particularly for early problems, a number of design tools were made available. These included advice on option evaluation such as considering possible solutions for 2 minutes, 2 hours and 2 days in successive cycles of refinement (Gillie et al. 2014); and guidance on rapidly estimating rough sizes of engineering components (Toolbox 2014).

To encourage debate and reflection on the course material, comment and feedback was given throughout the course on students' work by both students and staff. A variety of techniques were used including comments by teaching staff (written and spoken), discussion in class, and critiques of one group's work by another. This last was most effective when done in a structured way. For example, as part of a design and build project, students were asked to design a crane to be built from balsa wood and then present their design in the form of drawings to another group to build. Thus each group designed a crane, presented their design as drawings, interpreted another group's drawings and built a crane as a result. At the end of this groups met to discuss what had been successful and what hadn't in each other's designs.

The second aim, of developing students' confidence of using a range of engineering tools that are useful in design, was met largely by self-led learning, encouraged by setting design problems in which the tools would be useful. The thinking behind this approach was that the relevant tools did not lend themselves well to traditional lecture delivery. For example, developing sketching skills is much more effectively done by exchanging ideas about designs in sketch form than by receiving formal instruction. The tools presented as useful were sketching, Excel as a calculation tool, and (as above) using approximation and rules of thumb for initial estimating. At the early stages of design formal drawings are not normally appropriate and so use of Autocad and similar was deliberately discouraged. By contrast sketching and informal communication of ideas is a powerful mean of communication that is often overlooked in traditional degree programmes. In this course it was encouraged as part of a broad attempt to develop students' communication skills.

The assessment of course was closely aligned with the emphasis on learning cycles and communication as important areas. In addition it was recognized that early cycles of problem solving which were deliberately intended as practice runs should not receive significant marks otherwise creativity would be stifled (nominal marks were awarded to encourage full engagement). The course was assessed in two ways: direct consideration of students' work (submitted in portfolio form at the end of the course), and judgment of students' own reflection on how their understanding of problem solving and design had developed during the course.

3. COURSE CONTENT AND STRUCTURE

Full details of how the course was structured are given in Table 1 below

Week	**Activity**	**Comments**
1	What is design?	- An initial discussion of design and several 15 minunte design problems undertaken as a whole class. - Facilitation by course lecturers.
2	Use of design tools and informal engineering communication	- Introduction to approximate sizing, sketching and informal engineering communication. - Further design problems taking about 1hr that required use of these tools. - Design, communicate and build a balsa wood crane.
3		
4		
5	New build project	- A more challenging design problem examining how a school system in rural Ghana should be developed. - Use of various tools to aid design development.
6		
7	Design calculations	
8	Upgrade project	- Consideration of how a water supply at a Scottish rural estate should be developed. - Full range of stakeholders considered. - Comparable in detail and depth to a commercial early stage design project.
9		
10		
11	Final discussion and	

	portfolio submission	

4. OUTCOMES AND EXPERIENCE

Student experience of the course was carefully monitored by several questionnaires and also by exercises that formed part of the material of the course that prompted reflection on the design process by students. Since staff spent considerable time with students in a project environment it was also possible to obtain a clear impression of how the course was working by observing students and holding informal conversations with them, both individually and as groups. Teaching staff were convinced that the course was a success that ran well and achieved its aims. Formal end-of-course student ratings were exceptionally positive. From observing the class and analyzing student feedback and portfolio work, a number of notable points became apparent:

The class as a whole was initially very reluctant to talk openly about ideas in public. Early exercises were presented as problems on a whiteboard and the class were encouraged to approach them collaboratively as a group. Despite strong encouragement by staff and explanations of the intention of social learning, it took several weeks for students to be fully confident speaking about their ideas. This reluctance was highlighted by students in questionnaires, as was the transition to being more comfortable expressing their ideas. A number of comments in questionnaires highlighted that students who made this transition valued it as an outcome of the course and appreciated their communication skills had been enhanced. By contrast, staff noticed that some students did not ever fully become comfortable with either open discussion of ideas or even group work.

Related to students' developing communication skills was a development in their understanding of what conceptual design is. Students were asked to define conceptual design in the first class and again at the end of the course in their portfolios. Early descriptions were mixed and ranged from statements about design being lots of calculations to comments on creativity and imagination. The class emphasized problem solving, communication and creativity so it was encouraging that some students' portfolios highlighted these points (indeed some embodied them with, for example, diagrams showing design as a branching tree). It was further encouraging that some students have been able to subsequently use portfolios to obtain summer placements with employers. However, a few students seemed to have entirely missed the purpose of the course with final portfolios focusing on detailed calculations and demonstrating poor communication skills. Such a split in students responses perhaps reflects a range of levels of intellectual growth among the class along the lines described by Felber and Brent (2004) who, summarizing many earlier authors, highlighted various stages of understanding from "absolute knowledge" (expecting unique, authoritative answers to problems) through to "contextual knowing" (realizing many problems will have a range of answers and that selecting an appropriate one will require judgment and weighing evidence).

Student comments were similarly revealing. For example, positive comments included "Totally different way of learning", "A good chance to see the bigger picture and enhance personal skills that could be used in the future" and "It uses my imagination. I feel more creative". All these comments suggest many students engaged with and understood the purpose of the course. By contrast negative comments included "[the course could be improved by] making marking criteria more detailed", "Often we spend time doing stuff that was not actually relevant" which both suggest some students had missed the purpose of the course and were expecting problems with "right" answers. This in turn suggests that in future years more effect still is needed to clarify the course aims by staff in early classes. This need and also the challenge of effectively teaching classes with a range of intellectual development, particularly when using project work, was also highlighted by Felber and Brent (2004) and Felder (1997).

It was assumed that students would be familiar with the basic use of spreadsheets and that it would be possible to focus on more advanced techniques for using them for engineering calculation and communication in class. However, it rapidly became apparent that, despite student assertions to the contrary, very few students had used spreadsheets for more than the most basic types of data entry and that time was required to outline concepts such as use of formulas, cell-naming and formatting. This severely curtailed the extent to which spreadsheets could be introduced as a design tool and required teaching to focus on basic introductions to concepts instead.

Similarly unexpected was students' reluctance to use the web effectively as a research tool. Background understanding relevant to the design exercise concerned with developing a school system for rural Africa could easily have been obtained from web-resources but few students attempted more than very superficial research in this manner despite encouragement to do so. This raises questions about whether specific guidance on web research should be given early in degree courses, similar perhaps to traditional guidance on using library resources for project work.

5. CONCLUSIONS

The changing economic and technical environment requires corresponding changes in higher education and certainly within civil engineering design education. The experience of developing and delivering a new course that attempts to respond to globalization and automation in the design process and also to emerging changes in higher education (e.g. MOOCS) has been described. It was found that introducing high-level problem solving concepts via social and project learning can be highly effective and well-received by students. Care is needed to ensure students understand and participate in what will for many be the unusual experience of dealing with ill-defined problems with many possible solutions. Encouraging students to think about the nature of what they are attempting, both individually and collectively, helps with this understanding. Informal communication of ideas and social learning will also be unfamiliar to many and courses must be carefully designed to ensure as many students as possible are able to develop skills in these areas. The level of student ability with software packages and using web-based resources for research should not be over-estimated.

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