Engineering Education: How to Design a Gender-Inclusive Curriculum

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Despite recent efforts to increase the numbers of females in engineering courses, the proportion has plateaued at an average of less than 20%. To increase the proportion further many believe that the way engineering courses are structured and presented must be changed. Demand for change in engineering education is also coming from a number of other directions as has been demonstrated in recent surveys of engineering graduates and engineering employers.

Despite the lack of research on the interaction of gender and the nature of engineering courses, there has been much research in closely related fields such as secondary school science and mathematics. In general, this work has shown that girls are more interested in science if the total context rather than isolated technical tasks are emphasised.

Engineering courses should be changed so that they better meet the expectations of employers and graduates. This can be done in a way which also makes them better suited to female students. Content of courses should be pruned to eliminate the overload. Engineering topics should be treated in a total context which includes social, environmental and political considerations as well as technical aspects.

1 INTRODUCTION

Engineering Education in Australia is currently the subject of a number of high level reviews. One is the major review of engineering education in Australia which the Australian Federal government announced in November 1994 and which will be carried out jointly by the Institution of Engineers Australia, the Australian Council of Engineering Deans and the Australian Academy of Technological Sciences and Engineering. A second is the Women in Science Engineering and Technology Advisory Group which was established in May 1993 and which has just released a discussion paper which recommends closer attention be given to gender inclusive teaching (1). In this paper we suggest ways in which engineering education should be changed to encourage a greater participation of women in the profession. As there has been little or no direct research on the interaction of gender and curriculum content and methods of presentation and assessment for university engineering courses, we draw on indirect evidence from other fields such as mathematics and science.

2. WOMEN IN ENGINEERING

Over the last decade or so there have been many initiatives in Australia and overseas to encourage girls to become engineers (2). These have usually involved making school girls aware of the possibility of engineering as a career and/or offering some emotional support for women engineering students. They have not involved any restructuring of engineering courses to make them more women-friendly. After major increases in participation during the eighties, enrolments have more recently plateaued and in some cases declined in the nineties. Currently the participation of females in undergraduate engineering course in many Western countries is between 10% and 20% with higher participation in some specific disciplines or universities.

Many women involved in this field believe that, to increase the participation of women further and to treat equitably women engineering students and practising engineers, changes will have to be made to both undergraduate engineering courses and the structure of the engineering profession.

In February 1994, an international conference entitled "Engineering Education and Professional Practice: Developing Gender-Inclusive Models" was held in Leeds, England (3). Thirty invited participants from sixteen different countries attended. Many personal opinions were expressed about what a women-friendly engineering course would be like. For example, many people, drawing on extensive personal experience, felt that making the curriculum more socially relevant would make courses more interesting to female students. However, a major recommendation of the conference was that research should be carried out in this field and some research projects have since begun. The results from this work are not yet available. In this paper we draw on indirect evidence from other fields to give indications of how a women-friendly engineering curriculum is likely to differ from typical Australian engineering courses at present.

3. RESEARCH INTO GENDER AND MATHEMATICS

In the past many studies have shown that, although there is considerable overlap in the performance of males and females, on average, males outperform females in traditional mathematics tests. However, more recent research has shown that the gender difference depends very much on the assessment measure used.

3.1 Gender Difference in the Victorian VCE Mathematics Examinations

Rowley et al. (4) carried out a detailed study of the performance of high school students in the 1992 Victorian Certificate of Education (VCE) mathematics units. In 1992 there were six different units offered in mathematics. In each unit students were required to complete four Common Assessment Tasks (CATs). The nature of these tasks were very varied. CATs 1 and 2 are longer-term projects are attempted primarily outside school hours and have a strong language component in the presentation of the final product. In contrast, CATs 3 and 4 are timed assessment tasks, are done in school under examination conditions, have a much lower language component and are marked externally.

The results in figure 1 are typical of performance on the four CATs in each of the six units. A very clear gender pattern is apparent. Generally, females outperformed males in CATs 1 and 2, with the pattern reversed for CATs 3 and 4. Because of the large numbers of students involved, the differences shown in the graph above are statistically significant ($p < .01$)

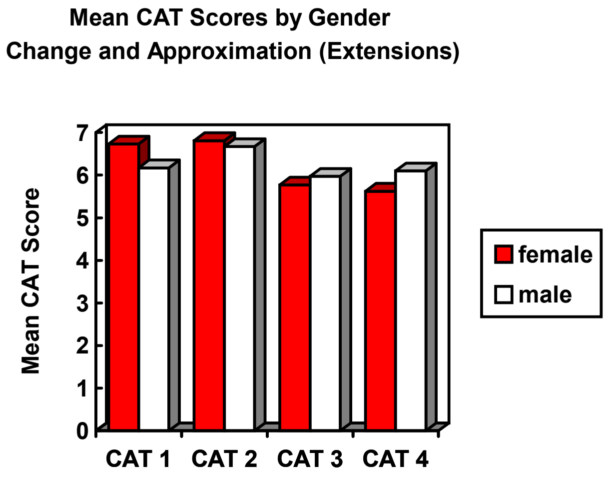

Figure 1. CAT score by gender for VCE unit Change and Approximation (Extensions) 1992

3.2 Gender Difference in 'Word Problems'

Johnson (5) conducted a series of experiments into gender differences in problem solving by administering a variety of tasks to students enrolled in a first year psychology course. He found that males consistently outperformed females in the type of problem which he called 'word problems.' A representative example of this type of problem is

> A snail starts at the bottom of a well 12 feet deep and crawls up 4 feet each day. Each night, however, the poor thing slips back 3 feet. How long will it take the snail to reach the top of the wall?

He concluded that much of the difference in performance was due to the greater spatial ability of the males. The difference in performance between males and females was halved for those word problems which included a diagram.

3.3 The Dependence of Gender Difference on Concepts involved in Questions

Difference in performance between the sexes in mathematics tests depends not only on the assessment mode but also on the precise concepts covered in each question. Bradberry (6) analysed the performance of school students in the English 16+ examination and found the widest discrepancy in favour of males in questions concerned with scale or ratio, spatial problems, space-time relationships and probability.

3.4 The Potsdam Experience: A Success Story for Women Students in Mathematics

The State University of New York College at Potsdam has been unusually successful in attracting and retaining female students in its Mathematics courses. In 1983 60.4% of all Potsdam's mathematics degrees were awarded to women compared with 43.8% nationally for the US. Rogers (7) conducted a study into the reasons for this success and found that there were no particular efforts to attract female students to Potsdam and no specific adaptations to meet their perceived needs. She concluded that the success at Potsdam was due to the teaching methods used which she described as 'teaching as coaching'. The staff selected topics carefully and recognised that not everything could be 'covered' in class. This meant that the students had time to play with the ideas in mathematics and construct their own meanings and understandings. Students were able to discuss problems with staff and learn by a process of trial and error with the staff prepared to give advice as required.

4. RESEARCH INTO GENDER AND SCIENCE

A paper by Harding (see reference (3)) summarises recent research findings on girls and science. These included a number of different studies into the reasons why girls chose, liked, or continued with science.

The conclusions of some of these studies are:

- Girls are more likely to choose science if it is packaged to include social implications.
- More girls choose to continue with physics if previous physics courses relate to 'their real life experiences, to human needs, to environmental issues etc'.
- Within a set task girls tend to identify different problems. One study of secondary school students in England found that 'Typically girls took account of the circumstances within which the task was set whereas the boys, as a group, considered the task in isolation apart from its context.'
- Girls tend to work more collaboratively. In one experiment 'the boys tended to negotiate time on the computer and each worked separately on the problem while the girls in a group collaborated together, exploring and discussing many aspects of the task.'
- Girls have different reasons for regarding science as important. In one study, girls felt a science course was important because it helped them 'understand the world' while for boys a more important factor was that it 'helped with careers'.

Again and again the theme recurs: girls are interested in science in its social context; whereas boys tend to be more interested in science as an end in itself.

Harding also summarised some findings on the interaction of gender and assessment.

- 'Multiple choice or so called objective tests favour boys.'
- 'The use of an assessment mode that allows candidates control over how they respond (eg. course work or project work) is likely to be more gender fair than others'.

These findings are consistent with those reported Rowley et al (5).

5. ENGINEERING COURSES IN AUSTRALIA

If the engineering education system, as it exists, was judged by all to be totally successful, there would be little justification in suggesting changes which made courses better suited to women but which resulted in graduates who were less qualified to work as engineers. However, there is evidence of discontent with the current state of engineering education from a number of areas.

5.1 Course Experience Surveys

Each year the Graduate Career Council of Australia distributes a 'Course Experience Questionnaire' to students who have just completed university courses. The survey includes most Australian universities (8). The questionnaire includes a range of questions concerning the students' experience of their courses. The questions are grouped to give results on a number of scales: the Good Teaching Scale, the Clear goals and Standards Scale, the Appropriate Workload Scale, the Generic Skills Scale. One item, the Overall Satisfaction item, was not grouped with any others.

The students' fields of study were grouped into major and minor classifications. 'Engineering, Surveying' is a major classification. Civil/Structural Engineering, Electrical Engineering and Mechanical Engineering are the three minor classifications within the Engineering/Surveying major field for which results are listed in the report.

In 1992, there were 1744 responses from those who had completed bachelor's degrees (pass and honours) in the Engineering/Surveying major field of study. This consisted of 1531 males and 213 females. The Engineering/Surveying students gave slightly lower ratings than the average for all students on the Overall Satisfaction Item, the Clear Goals and Standards Scale, and the Appropriate Assessment scale. They gave a slightly higher than average rating to the Generic Skills Scale. However, the ratings on the Good Teaching Scale were worse for Engineering/Surveying than for all but one other major field of study and for Appropriate Workload Scale it was rated worst of all.

When minor fields of study were considered, Electrical Engineering was rated the worst of any minor field of study on the Good Teaching Scale and second worst on the Appropriate Workload Scale.

In summary, engineering students on average gave lower rankings for their course than the average for all students. The low ratings on the Appropriate Workload scale and Good Teaching Scale indicate that engineering students felt that their courses were overloaded and badly taught.

5.2 Employer Perceptions of Graduate and Professional Engineers

In 1993 a survey of engineering employers by Bitcon (9) was sponsored by the Australian Department of Employment, Education and Training to assess the future employment opportunities and skill requirements for graduate and professional engineers. The survey involved over fifty organisations, many of them employing large numbers of engineers.

The conclusions were:

> "The vast majority (over 97 per cent) of senior executives interviewed were of the opinion that their engineers did not have the required range of sufficiently developed skills and preferred work experience to carry out these future roles to an acceptable level of competence. The skills in most urgent need of attention were found to be in the following areas:
>
> - Theory and Cross-Discipline Areas
> - Practice Skills
> - Management Skills
> - Personal and Interpersonal Skills"

The 'Practice Skills' which were identified as particularly lacking were Specifications and Contract Management, Planning and Resource Management, Computer Use, Manufacturing and Testing, and Environmental, Heritage and Cultural Issues.

A survey by Hessami and Eley (10) of Australian engineering employers had similar findings. They concluded that 'while there seems qualified satisfaction with the technical knowledge of recent graduate employees, there is need to improve their skills at communication and working cooperatively in an industrial environment.'

6. SUGGESTED IMPROVEMENTS TO ENGINEERING COURSES

6.1 Reduction in Undergraduate Course Content

How should engineering courses be changed to meet all these demands? Recent engineering graduates feel that their courses are overloaded. Employers are in general satisfied with the technical knowledge of graduates but find that they are lacking in other skills, such as, communication and working cooperatively. Both of these problems could be solved. The first and most important change should be to reduce the amount of technical material 'covered'. To achieve this it must first be recognised that it is no longer possible to include everything that may be of use to an engineering graduate. The emphasis should be changed to treating a smaller number of topics in a way which allows time for the students to understand the concepts rather than resort to rote learning, and allows a broader approach which includes the total context in which engineers work rather than only the technical one. Real world examples should be included from the start.

The courses which would result would also be more attractive to female students and be more closely matched to their learning styles and skills.

To achieve these aims the typical structure of engineering courses which concentrate heavily on mathematics, science and engineering science in the early years and leave applications and project work to later years will have to be reevaluated. Within a lecture based structure there are examples of this being achieved by using a systems or top down approach (11). A more radical change would be to move to a problem-based learning approach as many medical schools have done (12).

6.2 Life Long Learning Skills

The Bitcon (9) survey related to all graduate engineers many of whom would have graduated some time ago. Their lack of required skills therefore indicates not only shortcomings in the knowledge acquired as undergraduates but also in the abilities of graduate engineers to acquire the knowledge and skills required to perform adequately the work they are employed to undertake.

Careful attention should be given in undergraduate courses to developing the students' own life long learning skills. In the past this would have meant an understanding of mathematics and science, but in the future an ability to access information and recognise and master what is important will be equally important skills.

To achieve this undergraduate courses should be designed to develop students knowledge of the sources of information important to their field of study. At present this information is available mainly in the print media but increasingly will be available in electronic form.

6.3 Assessment Methods

It is a well established finding (13, 14) that the learning of most university students is closely tuned to the assessment tasks which they are set. This means, if new and different skills are required of engineering graduates, courses must be designed so, these skills are required to pass the set assessments.

Traditionally, formal written examinations form the major component of assessment in Australian undergraduate engineering courses. These do not require the skills which employers have highlighted as lacking in engineers and are not like typical tasks performed by practising engineers. Furthermore, the problems set are often similar to the 'word problems' which Johnson identified as being a task in which males outperform females. Thus, typical engineering examinations could be construed as an unnecessary hurdle which may disadvantage female students to a greater degree than their male colleagues.

Assessment measures which required the broader range of skills identified by the employers would also match the skills and preferences which have been identified in the research on girls and science: the interest in social implications, the concern for human needs and environmental issues, the way girls "take into account the circumstances within which a task is set", the way girls tend to work more collaboratively.

Many engineering educators will protest that such assessment measures are much more time consuming and that formal examinations are 'more efficient'. However, if these changes are done in conjunction with the reduction in course content which we also recommend, substantial improvements should be possible without any increase in teaching load for academics.

6.4 How to Encourage Change

The current introduction of quality measures within Higher Education should encourage some of the changes we suggest. Another powerful force for change in engineering education is the Institution of Engineers Australia accreditation process. Engineering Faculties recognise how important it is to their students that their degrees be accredited and, therefore, put considerable effort into making courses suitable for accreditation. It is suggested that the Institution of Engineers consider how the accreditation process could be improved so it takes more account of the views of recent graduates and engineering employers.

7 CONCLUSIONS

Typical engineering courses are poorly matched to the the learning styles of female students. The heavy dependence on formal examinations may also disadvantage them. The amount of material 'covered' in courses should be reduced and topics treated in a total context which includes social, environmental and other issues as well as purely technical matters. Time should be available for students to explore topics and develop their own understanding. These changes would improve the quality of learning for all students, both male and female. They would also result in graduates better suited to the requirements of the current employment market and better able to contribute to Australian society in many other ways.

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KEYWORDS

Engineering Education, Engineering, Teaching, Engineering-Professional Aspects, Women in engineering, gender and assessment, gender and learning, Gender-inclusive curriculum,