Some Lessons from a Decade of Teaching Ethics to Undergraduate Engineering Students*

Iain Skinner, Iain MacGill, Hugh Outhred
University of New South Wales

1. Introduction

Engineering was defined as 'the art of directing the great Sources of Power in Nature for the use and convenience of Man' in Thomas Tredgold's opening address at the foundation of the British Institution of Civil Engineers in 1824. A more recent definition, adapted from Wikipedia (2006) reflects the greater emphasis now placed on the social context of engineering:

> *The application of scientific and technical knowledge to solve human problems. Engineers use imagination, judgment and reasoning to apply science, technology, mathematics, socio-economic factors and practical experience in a systematic process of designing, creating and operating socio-technical systems to meet practical human needs.*

Engineers work at the interface between knowledge of the physical universe and the needs and desires of people. This is their special skill. How ought they to use it? Circumscribed by appropriate ethical guidance, of course.

We begin our discussion by considering whether engineering ethics is a special case of professional ethics that therefore requires specific attention by the engineering profession. Having argued that it does require such attention, we consider engineering ethics from the perspective of its professional associations and those studying to be engineering professionals. We conclude by introducing one course in which ethics is taught to undergraduate engineering students and briefly review how it has been received.

2. Engineering Ethics: A Special Case of Professional Ethics?

Engineers share with other professionals the characteristic, amongst other things, of being in a position of public trust. Engineering generally ranks reasonably high in public surveys about the trustworthiness of professions (see, for example, NSF, 2006). A profession possesses and can, in some ways, be said to guard a special body of knowledge, meaning it alone can determine how to use this knowledge; that is, what constitutes correct professional practice. This means that the members of the profession must be guided not only by externally imposed rules, but also be engaged in significant self-regulation. We see the need for specific professional ethics to provide guidance to the individual practitioner making a judgment in a unique situation. On one hand, engineering ethics is merely another example of professional ethics; on the other, it does have some very distinctive features.

In the medieval period, fields now called engineering fell within what were known as the Mechanical Arts. The Seven Mechanical Arts, intended as a complement to the Seven Liberal Arts, included weaving, black-smithing, war, navigation, agriculture, hunting, medicine and the *ars theatrica*. The engineering profession has a particularly military origin – civil engineering was so called to distinguish it from military applications – and its relationship with society continues to evolve.

The Victorian Engineers were superstars of their day and champions of techno-optimism. The term 'engineer' originated from the Latin *ingeniator*, meaning 'the ingenious one'. Leonardo da Vinci bore the official title of *Ingenere Generale* (Auyang, 2004). This driving role in technical innovation, and technology's driving role in our society, qualifies engineering as social experimentation (Martin & Schinzinger, 1996), raising questions about society's consent for engineering. For example, in the practice of medicine there are quite strict legal procedures applying to the conduct of experiments and the introduction of new therapies. This differs from the case of engineering, wherein practitioners usually have considerably more freedom to develop new technologies and face a minimum of legal constraints on their subsequent introduction. As all innovation necessarily proceeds with incomplete knowledge, any new technology may have an unexpected consequence. With limited legal controls, this uncertainty imposes a high moral responsibility on engineers. Periodically, with particular technologies, the public has expressed concerns about what it perceives as unaccountable technical elites. Nuclear power is a pertinent example. For example, the troubled French Superphoenix fast-breeder reactor program had:

> *an incredible series of 'impossible' accidents ... two of which had been allotted an official [engineering] probability of occurring 'not more than once in 10,000 to 100,000 years'* (Marcellus, 1992).

Engineering innovation can also have far more positive outcomes: Google was founded by a computer engineer and a computer scientist with the informal corporate motto 'Don't be evil.' Even so, however, there are many ethical questions raised by such search engines.

Furthermore, the breadth and complexity of engineering continues to grow. For example, The University of New South Wales offers a Bachelor of Engineering in some twenty areas. Engineers can end up in a wide range of roles during their careers. A recent survey of Australian engineers found them working in management (35%), design (13%), project study and analysis (11%), production (11%), research and development (9%), and sales and marketing (2%) (APESMA, 2006). Such a wide range of activities differs from many other professions - for example, dentistry or pharmacy - in which there is a very limited variation in jobs. This makes it more difficult to provide specific, prescriptive guidance about an engineer's behaviour.

Finally, engineers often play a complex role in decision-making within organizations. Many engineers are not the final authorities on technologies. They devise, they advise, but they generally neither finance nor authorize; and particularly not in organizations based around the 'management imperative'. In practice, therefore, the engineering decision is usually about 'how', but not often about 'ought'. Nevertheless, an 'ought' decision necessarily precedes any resolution on 'how', because it is part of the design process. For the decisions that are solely for engineers to make, another challenge for general professional ethics is that engineering often involves considerable teamwork and shared responsibility for decision-making, raising group ethics questions. Potential problems here include:

- The technical knowledge hierarchy may not coincide with the organizational hierarchy, leading to difficulties in reaching appropriate assessments of risk (as perhaps demonstrated in the lead-up to the first space shuttle disaster).
- Ambiguity in accountability may dilute individual feelings of responsibility for the outcomes (as might be seen with members of a team working on different aspects of military hardware).

3. Engineering Ethics: The Role of the Profession

All of the above reasons argue for engineering ethics being a special case of professional ethics. The Institution of Engineers Australia (IEAust, trading as Engineers Australia) represents the engineering profession within this country. One of its roles is to 'champion professional and ethical conduct' and it has a formal code of ethics (IEAust, 2000), the preamble of which reads:

> *All members of the IEAust, in the practice of the discipline of engineering, are committed and obliged to apply and uphold the cardinal principles of the Code of Ethics, which are:*
>
> - *to respect the inherent dignity of the individual;*
> - *to act on the basis of a well-informed conscience, and*
> - *to act in the interest of the community.*

We shall return to this code later. In practice, Engineers Australia can only have a limited role in encouraging ethical behaviour as it has much less control over employment within the profession than do numerous other professional bodies. Typically, organizations do not require their engineers to be members, only that they be eligible for membership. Part of this reflects engineering's truly international focus. Perhaps IEAust's key role in promoting engineering ethics is through its role as the accrediting professional body for engineering education.

From the 1980s, there has been a recognized need for ethics to be integrated into the syllabus of an engineering degree. This is identified by the documentation of the accrediting professional bodies, both in Australia and elsewhere, that talks of students needing to develop 'an ethical awareness'. Ethics is seen as intrinsic to the self-regulation of a profession and, hence, a necessary part of any Bachelor of Engineering (BE) syllabus. Ethics is also seen as a convenient vehicle to introduce engineering students to non-technical patterns of thought and so improve their capacity for interactions in the community where they serve. IEAust's accreditation policy states:

> *A typical four-year professional engineering program should have the following elements:*
>
> - *maths, science, engineering principles skills and tools (40% or more of course content),*
> - *engineering design and projects (20%),*

- *engineering discipline specialisation (20%),*
- *integrated exposure to professional engineering practice, including management and professional ethics (10%,)*
- *more of above elements or other elective studies (10%)* (IEAust, 2006)

With regard to professional ethics,

> *The students must be exposed to professional engineering practice integrated throughout their program to enable them to develop an engineering approach and ethos, and to gain an appreciation of professional engineering ethics. The purpose of this is to facilitate their entry into the profession and to better prepare them to be able to develop the attributes ... it must include:*
> - *use of staff with industry experience,*
> - *practical experience in an engineering environment outside the teaching establishment,*
> - *mandatory exposure to lectures on professional ethics and conduct.* (IEAust, 2006)

However, after more than two decades of such thinking and a push for the implementation of such policies, it seems reasonable to say that there has been only mixed progress. When one looks at many engineering programs in Australian universities, the kindest one can say is that it is not obvious how such an aim would be achieved. This lack of progress, not just here but globally, worries many. As recently as December 2005, the IEEE's magazine, *The Institute*, had a lead article explaining how straightforward it is to bring ethical challenges to undergraduate engineers (Jones, 2005). The Global Colloquium on Engineering Education in 2005 (ASEE, 2005) had a professional ethicist as a keynote speaker and several papers about 'transforming the undergraduate syllabus' by the novel inclusion of discussion of ethical problems.

We now consider how this has been approached by the School of Electrical Engineering and Telecommunications at The University of New South Wales (UNSW).

4. Teaching Engineering Ethics at UNSW

As with all engineering education in Australia, the programs offered by the Faculty of Engineering at the UNSW are accredited by IEAust. The University also has specific educational objectives including:

> *to ensure that students examine the purposes and consequences of their education and experience at University, and to foster acceptance of professional and ethical action and the social responsibility of graduates.*

Most engineering schools don't have a dedicated course of study for ethics, instead they 'integrate' ethical education into other courses. Within the Faculty at UNSW, there is a typical mixture of ways ethics is presented within the program of study. Table 1 provides a summary of the situation.

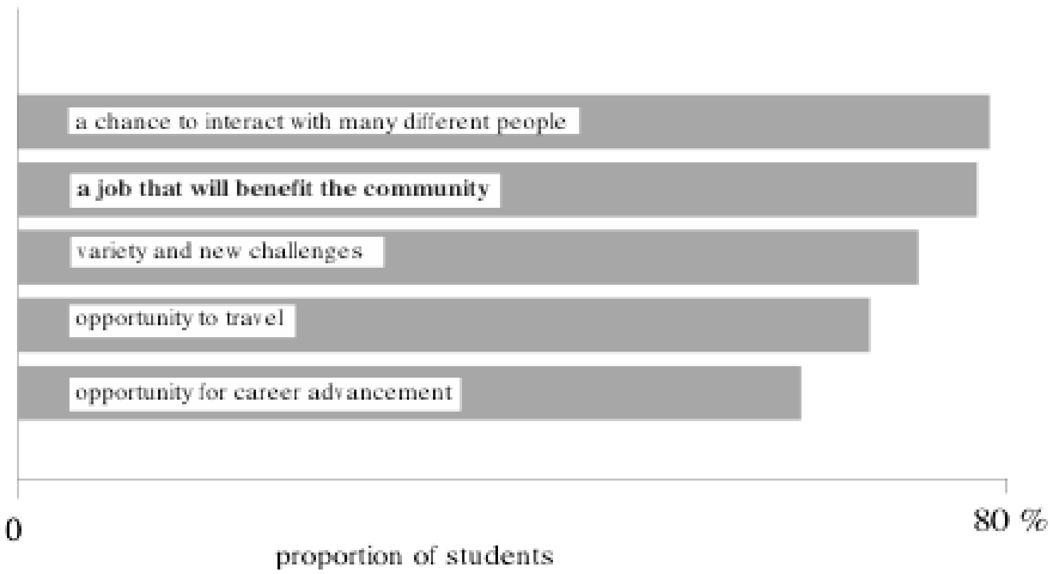
The School of Electrical Engineering took an early decision to teach professional ethics formally in a stand-alone course and has been formally teaching this now for more than a decade. After describing the current arrangements for this course and the way these have changed over time, in the next section we will consider some of the lessons that can be drawn from this experience to date and how these contribute to some of the key debates in teaching engineering ethics.

Table 1: How Ethics is Included in BE Programs at UNSW

BE Programs	How Ethics is Included
electrical, photonics, photovoltaics, renewable energy, telecommunications	Ethics & electrical engineering practice (year 4 of course, 12.5 % of session)
bioinformatics, computer, software	Professional issues & ethics (year 4 of course, 25 % of session)
chemical, industrial chemistry, petroleum	Social issues in science & technology (year 3 of course, 12.5 % of session)
civil, environmental	Civil engineering practice (year 1/2/3/4, each 25 % of session)
aeronautical, manufacturing, mechanical, mechatronics, mining, naval, surveying	not clear

The School of Electrical Engineering took an early decision to teach professional ethics formally in a stand-alone course and has been formally teaching this now for more than a decade. After describing the current arrangements for this course and the way these have changed over time, in the next section we will consider some of the lessons that can be drawn from this experience to date and how these contribute to some of the key debates in teaching engineering ethics.

Figure 1
Top Five Considerations Important to HSC Students' Career Choice (Macquarie University, 2006)



Students currently receive a brief introduction to engineering ethics in their first year of study. This takes the form of two, one-hour discussion classes exploring the nature of responsibility. These students, new to tertiary study, are given (i) a case study illustrating an ethical failure in an engineering system and (ii) material related to plagiarism and intellectual property regulations. In each case, they are invited to explore the nature of responsibility. Part of the motivation is to highlight early in their education the importance of ethical issues. Many students react positively to this engagement with the ethical context of the profession. It is interesting to note that surveys of Australian Higher School Certificate students have highlighted that 'a job that will benefit the community' is one of their highest considerations in making a career choice (Macquarie University, 2006). The comparative importance of this is seen in Figure 1.

Most of the ethics teaching, however, is in the context of one specific and compulsory formal course: 'Ethics and Electrical Engineering Practice' (ELEC4011). Students of electrical, and related forms of engineering, complete this course in their final semester of study towards the BE. It represents a notional one-eighth of that half-year's workload. The course's formal, explicitly listed aims are that students will:

- learn how to comprehend and critically examine ethical arguments;
- identify ethical problems in an engineering context and formulate and communicate consistent, coherent responses to them;
- examine the social context of engineering; and
- explore an engineer's rights and responsibilities.

Teaching involves some formal academic input through traditional lectures, but the greater part is through facilitated debates between the students, in the context of small classes. The lecture program has reduced from what was originally 28 hours over the session to the current eight. Recently this has included two lectures by EE&T staff on ethics and professional practice, two by a guest lecturer from the UNSW Faculty of Arts on philosophy and ethical principles, a lecture by a member of the university's ethics panel, and three lectures by guests (from within or outside the university) exploring the ethics of issues of current concern. Over time these have included, amongst other topics, climate change, sexual harassment, transgenic organisms, stem-cell research, and the privatisation of national infrastructure. The reduction in lecture hours was a deliberate response to the students' expressed wish. They did not simply want to hear staff talk about topics; they wanted to argue their own positions on questions that they chose. In other words, the undergraduate engineering students saw some questions as important and wanted to engage in debates on ethics.

As lectures reduced in importance, they were replaced by interactive tutorials that now involve ten, two-hour classes in each of which there is a strict maximum of 16 students. We have experimented with larger classes (up to 24), but they have not succeeded in giving each student enough time on the floor. This is a significant change from the original program that included only five, one-hour tutorials of up to 25 students each.

Academic staff from EE&T lead the first two tutorial classes. The other eight are led by groups of students who must identify appropriate 'questions for the day', within a nominated topic area. These classes, therefore, involve ethical dilemmas of the students' own identification and definition. The topic areas change each year. Last year they included environmental ethics, workplace behaviour, engineering as social experimentation, intellectual property, automation and human dignity, regulation of the world-wide web, and precision-guided weapons. Note that the students attend tutorials with the same group of students for all ten tutorials. This is important. We notice that the students are more relaxed and confident about expressing their own ethical judgments and nominating dilemmas as they get to know each other and their tutor. Note, too, that we do not employ postgraduate students as tutors, but only staff at least one generation removed from the majority of the students.

One feature that needs stressing is the diversity in the student body of cultural background, educational experience, life experience, and academic ambition. It is only the age profile (rarely anyone outside 20 to 25) that is compressed. The UNSW engineering undergraduate student body is relatively diverse and continues to evolve. For example, in 2004 it was 20% female, 38% part-time, 30% international, and over 60% had a non-English speaking background.

5. Some Lessons from this Teaching

The first lesson to record is the considerable challenge in even evaluating this course. How ought it be assessed: against the demands of our student body; the engineering profession; professional ethicists? We have conducted some formal evaluation but comparisons are difficult. Is it appropriate to compare this against a mathematics course?

The abiding nature of those questions and the continuing evolution of the course structure mean that much of what we discuss here is anecdotal.

The role of ethical theory

Surveys of teaching engineering ethics have highlighted three general approaches: codes of ethics, case problems, and moral theory (Heckert, 2000). There is considerable debate about the value of teaching moral theory. Different ethical frameworks can provide different answers to particular issues. Some, including Bowden et al. (2006), have highlighted potential problems for engineering students.

> *Engineers and their training are often described as convergent – that is they employ analytical approaches that seek solutions. It is a training that is likely to find as unacceptable, a body of theory that does not provide answers or at best provides conflicting answers. A real problem to a teacher of ethics in engineering therefore is that students may reject the course due (to them) to the unsatisfactory and incomplete nature of the underlying theory* (Bowden et al., 2006).

In contrast, we consciously and explicitly teach four general models of ethical reasoning - duty, rights, virtues and utilitarianism - and ask the students to apply these in both the seminars and the formal examination. Our experience has shown that there is very little resistance to their use, although students don't always specifically apply them in their answers. We have observed some interesting patterns. There is a strong preference by many students for utilitarianism, perhaps because in engineering design they are trained to undertake cost-benefit analyses or perhaps reflecting consequentialist arguments being popular in wider society. Duty ethics, too, is widely preferred and this may be connected to the cultural background of many students having a strong Confucian influence. There is only occasional spontaneous reference to virtues.

To emphasise the contradictions present in ethical dilemmas, we actually require students to argue one side of an ethical issue using one framework and then the other side using a different framework. The students, long accustomed to the certainty of mathematical formulas, are initially suspicious of there not being a unique answer to ethical problems, but, after a few weeks, move beyond this and find it quite liberating for their imaginations.

The role of engineering codes of ethics

Some courses are structured largely around a relevant engineering association's codes of ethics. We provide IEAust's code to students and include it in one seminar exercise. Students often wonder if they have to memorise it – and are relieved when assured that they don't. We also draw their attention to codes' limitations generally. These limitations in the Australian context have been highlighted by others, including Bowden et al. (2006), and reinforce the importance of teaching beyond such codes.

The role of case studies

According to Heckert (2000), the most popular approach to teaching engineering ethics in the USA is the use of a catalogue of case studies. Bowden et al. (2006) argue for this approach and use an industry survey to identify key issues as guidance for an appropriate catalogue and associated study questions. However, it should be remembered that engineering students are accustomed to not only studying a set of experiments but also an accompanying, relevant unifying theory (hence our choosing of explicit study of the latter). We have used a less formal approach to choosing topics. Instead, we judge the students' reaction and learning over time, and replace those topics from which students do not develop their ethical reasoning, looking for newer opportunities as they arise in public debate, for example, nuclear power in 2006.

The use of a structured debate between groups of students in the first tutorial highlights the limitation of using case studies as a formal framework for their learning. In this classroom exercise, students are given a position to take and then must find their own supporting arguments. The course aim, though, is that they become more critical and flexible in their thinking rather than merely 'for' or 'against' a specific set of topics.

The role of internal versus external expertise

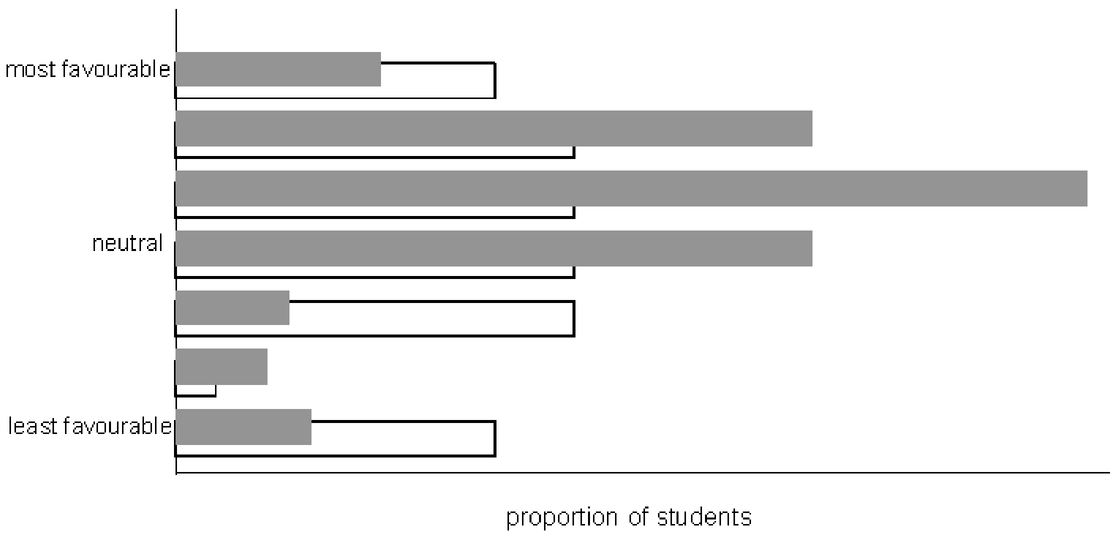
The success of this course relies on the assistance of people from outside the Faculty of Engineering. Seeking their help is consistent with the standard model for undertaking an engineering activity: we are used to sub-contracting for specific expertise in a project when we do not have sufficient skills.

First, when the course was introduced, the syllabus was designed with the active assistance of UNSW staff with professional expertise in the formal teaching of ethics and ethical reasoning. Second, there is always a need for external expertise to make the teaching more effective. Speakers with formal expertise in ethics (i.e., a more comprehensive perspective than merely applied to the engineering context) can and do provide a solid and convincing academic basis to persuade the students that formal thinking about ethics is intellectually respectable. There is also a need to engage people who come from a non-academic context and who can talk of what our students might see as 'real problems'. Students are very good at identifying lecturers who 'don't know their stuff'. Third, speakers with external experience are convincing evidence that real ethical dilemmas arise in real contexts, warning the students of what can happen and thereby motivating their current study.

The student experience

This is a compulsory course and teaching occurs before professional practice has commenced. The course poses an unexpected challenge to all students. However, we have learnt that students can, indeed, enjoy the active consideration of ethical questions. This is made easier when students bring their own problems for discussion. In earlier weeks, there is a tendency for students to resent the course as 'irrelevant' although 'a bit interesting', but this is overcome by the end of the teaching semester. Indeed, many students come to enjoy the course and one measure of our success is that students do the necessary work without realising it and 'don't count it as study like preparing for other classes.' Despite the generally positive assessment of the worth of such studies, students still express a lingering fear about assessment tasks that do not have a single, unambiguous, correct answer. And, of course, there are always a few who question how such a course will enhance their employment prospects!

Figure 2
To What Extent Would you Recommend that Another Student, Like Yourself, Study this Subject?



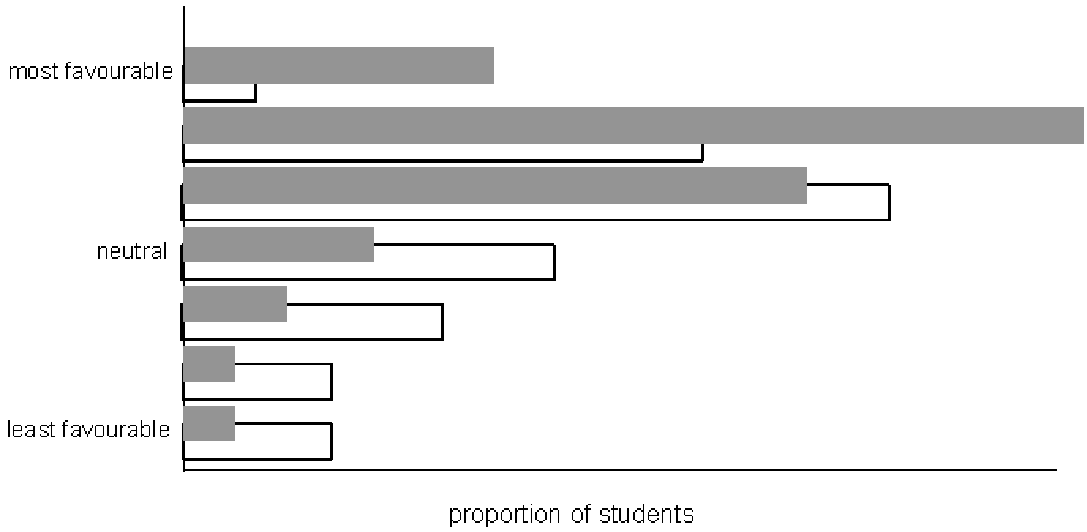
Solid bars 2003; empty bars 1996 (UNSW formal student surveys).

The anecdotal evidence supports the students seeing the course as both very interesting and relevant. Of course, we have completed formal course questionnaires. Figures 2 to 4 show some evidence supporting these contentions about the students' reactions to studying ethics. When compared with other compulsory courses, all these results, especially that in Figure 2, are very positive. It should be noted that an indication of the value the students place on the tutorial-seminars is seen by how positively they were endorsed in 2003 (Figure 3) compared to how indifferently in 1996, when there were only five. In interpreting this change, we should also note that there may be a broader discussion within society of questions related to professional ethics now than there was in 1996.

The staff experience

The inclusion of a formal course about ethics has not been enthusiastically received by all the School's staff. First, the course is expensive for the School, as only academic staff are rostered to facilitate tutorial classes. Second, many academics feel uneasy in teaching such non-traditional material, and understandably so. Some of them are unhappy about teaching material on which they are not considered an authority. Some believe their professional experience is inadequate for the task. Staff quickly determine whether they enjoy such a course and whether they ever want to participate again. This is not a course for the reluctant. Happily, there are those who, like us, enjoy the challenge and interaction with the students and so lead tutorials year after year. In the wider Faculty context, there is a suspicion of such interdisciplinary material 'diluting' the technical education of engineers. Academics can be more suspicious than the students.

Figure 3
How Helpful Were the Tutorials/Seminars?



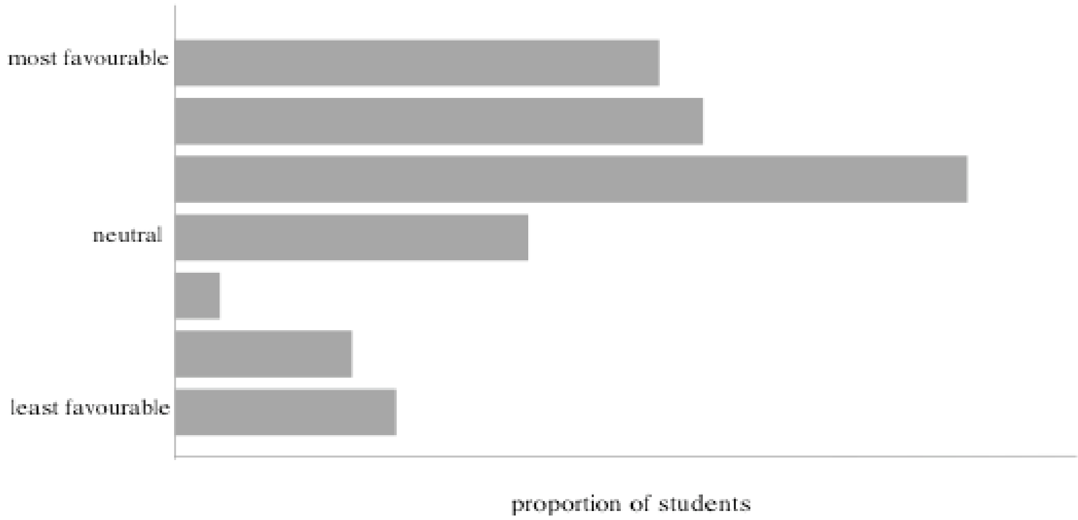
Solid bars 2003; empty bars 1996 (UNSW formal student surveys).

Assessment

Having a formal examination is Faculty policy. This course's exam includes open-ended questions with no specific answer expected. The students' formal presentations in tutorials are assessed and we have experimented with student peer assessment. While only a suggestion provided to the academic staff supervising the classes, it does lead to the students thinking more profoundly about the arguments and dilemmas their classmates present. The assessment of seminars is not designed to see if students think as they ought about certain questions. We find they better engage in ethical argument if they have the freedom to come to their own conclusions and test these against someone else's.

A challenge we have yet to meet is to test the students' ability with 'moral reasoning' before and after the course.

Figure 4
Is this Subject Relevant to the Degree Program?



Question not asked 2003; solid bars 1996 (UNSW formal student survey).

6. Where to from Here?

We are left with a wide range of questions and challenges. As noted above, there are difficulties in measuring the effectiveness of such a course. Also, it is difficult to balance the general and the specifically engineering content, as well as expertise, within the course. Should we be teaching engineering ethics or general professional ethics? The School's proposal for beyond 2007 is to integrate ethics with the students' study of management and business, returning to a more conventional approach for an engineering degree program.

We have yet to identify an entirely satisfactory way to manage cultural differences and, more seriously, language barriers. For many students, the very idea that they can determine what should be done is novel. Some students with poor language skills fear the emphasis placed on interactive learning.

In the wider engineering context we can think about many different questions. For example, what about post-graduate engineering students? It is not clear how and what form an education about ethics might take for postgraduate students who are, typically, studying a specific technical specialization or to prepare for wider roles and responsibility. In that case we would be educating students to be managers of engineering activities, with associated higher-level responsibilities. In that case, the student body would be even more culturally and demographically diverse than the undergraduates are.

Perhaps we need, too, specific training in engineering ethics for the engineering academics. Delivering this course has highlighted some of our own limitations.

For undergraduate engineering students, though, we feel it is appropriate to challenge them with a call to accept their social responsibilities when designing and to relate with others in an appropriately ethical (professional) manner. Overall the inclusion of a formal specialist course discussing professional ethics has proven to be worthwhile and successful, but with scope for further improvement.

*We thank Stephen Cohen, Damian Grace, John Kaye, and our many students who have helped us learn how to deliver an effective course in engineering ethics.

References

ASEE (2005). *4th ASEE/AaeE Global Colloquium on Engineering Education*, 26th-29th Sept. 2005, Sydney.

Auyang S.Y. (2004). *Engineering – An Endless Frontier*. Harvard University Press: Cambridge.

APESMA (2006). Professional Engineer Remuneration Survey Report.

Bowden, P., El-Zein, A. and Airey, D. (2006). 'Underpinning a Discipline-Specific Ethics Course', *AAPAE 13th Annual Conference Proceedings*, 12th-14th June, Sydney.

Heckert, J.R. (2000). 'Engineering Ethics Education in the USA: Content, Pedagogy and Curriculum', *European Journal of Engineering Education*, Vol. 25, No. 4.

Institution of Engineers Australia (2000). *2000 Code of Ethics*, available at www.engineersaustralia.org.au/about-us/discipline-complaints/code-of-ethics/code-of-ethics_home.cfm [accessed 14 Aug 2006].

Institution of Engineers Australia (2004). *Accreditation Management System*, available at www.engineersaustralia.org.au/about-us/course-accreditation/the-accreditation-process/accreditation-management-system-for-professional-engineers/accreditation-management-system-for-professional-engineers_home.cfm [accessed 14 Aug 2006].

Jones, W.D. (2005). 'Adding Ethics to Engineering Education', *The Institute*, Vol. 29, No. 4.

Macquarie University (2006). *Macquarie University Science Engineering and Technology Study*.

Marcellus, O. (1992). 'Breeding Disaster: France's Nuclear Power Program', *Multinational Monitor*, April.

Martin, M.W. and Schinzinger, R. (1996). *Ethics in Engineering*, 3rd ed. McGraw-Hill: New York.

NSF (2006). *National Science Foundation Science and Engineering Indicators*.

Wikipedia (2006) 'Engineering' available at www.wikipedia.org [accessed 14 Aug 2006].