Engineering Ethics Courses Reimagined

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Introduction

Ethical engineering practice and professional registration is regarded as the most effective way to ensure and maintain the safety of the general public. Of course the system is not 'fool-proof', with accusations of engineering incompetence, mismanagement and fraud found periodically in the public news. It is mandated that registered engineering schools educate undergraduate engineers to be technically competent and to behave ethically.

While ethics is often incorporated into first year engineering courses with titles such as 'Professional Practice' and 'An Introduction to Engineering', at Griffith University, Australia, ethics is also emphasized in a compulsory co-taught course for master's degree and undergraduate degree students in the 'Research Methods' course (Thiel, 2014). Thus the themes are re-enforced in subsequent courses. While most courses focus on plagiarism, there is ethics-related subject matter in other courses, including research and measurement related to human participants (sports instrumentation), sustainability (environmental engineering courses) and investigative surveys (construction management, enterprise safety).

Engineering undergraduate education rightly tends to focus heavily on technical skills. The result is that professional skills courses are unpopular and not seen as being as important by both educators and students alike. When courses are of less technical interest to students and there is the additional requirement to write paragraphs using logical argument, engagement with the material can be a major challenge. This view is also prevalent in master's degree studies.

A modified undergraduate course 'Research Methods and Statistics' and the new master's level offering 'Advanced Ethics in Engineering' were developed to gain the attention, trust and engagement of students in their respective engineering degree programs through new methods of learning and by addressing some of the latest ethical challenges facing engineers. Bustard (2018) suggested four methods that improved student engagement with ethics:

- Aligning the content with student interests.
- Using a pragmatic approach rather than a philosophical one.
- Addressing the full complexity of real-world case studies.
- Covering the content in an entertaining way.

Both courses focus on developing these professional skills but are centred directly on technical matters that are directly relevant to the individual's chosen engineering discipline and their selection of a particular project chosen within this field. The courses are designed for relevancy to the changing face of engineering practice and the changing world environment in which engineers must now practice. In this way we believe the engineering ethics education has been 're-imagined'.

The School of Engineering and Built Environment at Griffith University maintains accreditation through the five-yearly review process. In Australia, the EA code is mandatory for professional practicing engineers as part of the requirements for professional registration so that the courses described in this paper are mandatory. This is very important for international students as the Engineers Australia (EA) Code of Ethics (Engineers Australia,

2019) has similar content to other international codes of ethics (e.g. IEEE, 2019 and ECEC, 2008).

This paper will first outline the content of the modified undergraduate course (Research Methods and Statistics) and provide data derived from student course evaluations. Second, the six modules of the newly developed Masters-level course (Advanced Ethics in Engineering) will be outlined and student feedback reported.

Research Methods for Engineers

This course was initially developed at Griffith University for master's degree students, but since 2015 has become a compulsory course for third year undergraduates under the title 'Research Methods and Statistics'. The textbook (Thiel, 2014) is a short formulaic approach to generating a new research project from the existing, recent literature. The book was written for students whose first language is not English, but is generally accessible to all. The book is now recommended in various engineering schools around the world.

The structure of the course follows a sequence for each individual student:

1. Find a recently published journal paper in your engineering discipline.
2. From this paper develop a new research question and research hypothesis directed at improving the human condition.
3. Develop a research method and data collection protocol to statistically validate the hypothesis.
4. Review the research competencies required and develop an employment schedule, ensuring that the student only practices within their discipline and expertise.
5. Reflect on how this research result improves the human condition.
6. Develop a complete costing for the project.

Weekly worksheets and lectures are used to keep the students on-track as they develop their research proposal. Assessment is based on a statistics quiz (20%) and a preliminary written assignment (20%) with the following structure:

- Research title
- Abstract including a wide view of the problem, an hypothesis and a summary of how this research is of value to humankind
- Literature review leading to this new research
- Experimental methods
- Statistical methods

The formative feedback on this submission can be used for the final assignment (60%), where the research method is expanded and both the workforce and costs (time, dollars and resources) are introduced, and the general conclusion enunciated. The benefits to the community of undertaking this new research are a necessary component of the final document and emphasised throughout the course as defined in the Australian Engineering Code of Ethics.

The 50 minute statistics quiz is, perhaps, unusual as students are required to interpret statistical outcomes with very little requirement to calculate outcomes. Some examples of quiz questions include:

Q1. A data set showing the pH (dependent variable) of the solution inside a tank as a function of the mass of top soil added (*m* independent variable) in mine waste water ponds resulted in the following linear fit $y = -0.07x + 7.5$ with $R = -0.9$. Calculate the linear correlation coefficient R^2 and explain what this means. (3 marks)

Q2. From the equation in Q1, what mass of top soil must be added to achieve a neutral $\mathrm{pH} = 7$? Is this a reliable estimate of the mass of soil required? (3 marks)

Q3. If the mathematical function thought to describe the results from an experiment is expected to follow the equation $L(t) = 7 - A\sin^2(\theta)$, what would you plot on the *x*-axis and on the *y*-axis to be able to fit a linear correlation coefficient to the data if A is expected to be a constant? What would be a statistically convincing result? (4 marks)

Q4. An atomic force microscope is used to measure the oxide thickness of a semiconductor square sample. Equally spaced 10 × 10 measurements of thickness are made. What statistical technique would you use to prove that there is a thickness gradient of the oxide across the sample? (4 marks)

Q5. The number of native birds in the city areas is thought to be related to global warming (higher temperature, drought conditions in the country areas, and lack of population growth). Describe how you would test this theory statistically. (4 marks)

Thus, students are required to suggest statistical approaches to problems and to interpret statistical outcomes. The learning and teaching assumption is that statistical-based tools are common and relatively easy to use in computer resources such as MS Excel® and Matlab® (www.mathworks.com). The challenge is for students to outline what method to use and how to interpret the results from the statistical analysis. A practicing engineer must deliver creditable and competent outcomes based on a strong statistical foundation.

This course is directly related to the ethical requirements of all engineering projects by:

- providing research outcomes that are of benefit to society,
- seeking and attributing the contributions of others (including plagiarism), and
- ensuring that the workforce has the required expertise.

Student and Staff Reflections

In common with most engineering courses, perhaps most university courses, many students are driven only by assessment items. As the weekly workshops are unassessed, attendance is generally low. The consequence is that those students that do not keep up-to-date do poorly on the assessment items.

In 2018, anonymous student feedback from undergraduate students and the equivalent from master's degree students was collected through a survey containing the following questions:

1. This course was well-organised
2. The assessment was clear and fair
3. I received helpful feedback on my assessment work
4. The course engaged me in learning
5. The teaching team (lecturers and tutors) on this course was effective in helping me to learn

The questions were scored out of 5 points, with 5 (strongly agree) to 1 (strongly disagree). With a 25% response rate, undergraduate, postgraduate and on-line students completed the survey. Figure 1 summarizes their responses. The 5-point scale was converted to a total score out of 100.

According to student feedback, the course was well organised (average score of 82/100). Within the qualitative feedback, students highlighted that the course material, such as lecture slides, were well structured and a useful resource for their learning. Students found the personal feedback useful and constructive (average score of 85/100). The students' feedback also indicated the course was engaging (average score of 85/100), and it was highlighted that the course encourages critical thinking and analysis of information.

Students mentioned the importance of incorporating statistical methods into research studies, as they would contribute to convincing decision makers and different audiences with respect to the accuracy of the results obtained.

Students also provided feedback in terms of “things that can be improved” in future offerings. In particular, on-line students suggested a different assessment system by improving the on-line submission. They highlighted that workshops are difficult to undertake on-line. These issues have now been addressed.

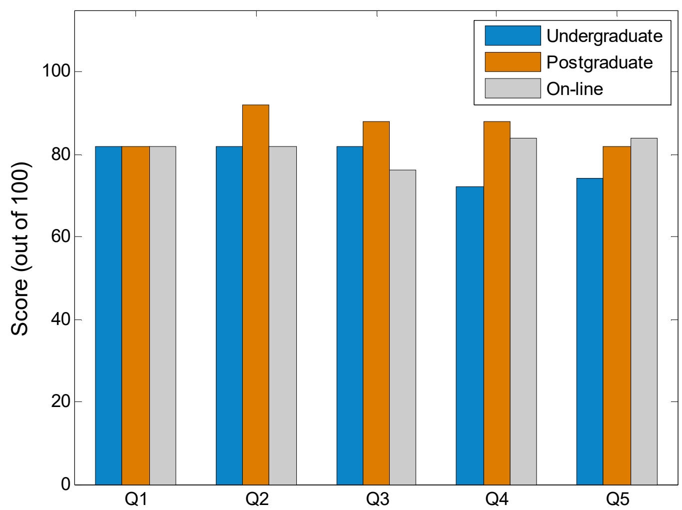

Figure 1: Anonymous survey response from undergraduate, postgraduate and on-line students. Questions 1 to 5 scored out of 100.

Advanced Ethics in Engineering

The Advanced Ethics in Engineering course is a master’s level, on-line (only) course, which was completed for the first time 12th October 2019. This course is part of a new degree program ‘Masters of Professional Engineering and Leadership’, in which only chartered professional engineers of five or more years standing qualify for admission. The degree consists of four courses commencing with the ‘Advanced Ethics’ course. The course is offered in a 6 week intensive mode for practicing engineers. The course consists of the following 6 modules (sub-topics are included in brackets):

1. Navigating the ethics challenges (Engineering Codes of Ethics, The origins of ethics).
2. An engineering response to sustainability (Design for the environment and the circular economy, Life cycle analysis, Product ownership, Ethical design and satisficing).
3. Digital data storage and privacy (What is big data? Privacy and State control, The use and mis-use of big data).
4. Biomedical interventions (Bionics, Exoskeleton support and assistive technology).
5. Sources of information (Combatting misinformation and other fake news, Working outside your area of expertise, Whistle blowing).
6. Artificial intelligence and the future of engineering (Artificial intelligence (AI), Machine learning, The future of engineering work).

The new material presented in this course is planned to challenge and engage practicing engineers in the very modern interpretation of the engineer’s role in a multicultural society, built upon a foundation of ethical principles. Table 1 lists some fundamental views from the literature including the vernacular expression (Module 1).

Module 2 considers the possibility of the manufacturer owning the product for its complete lifetime and requires its return to the company after obsolescence or end-of-life. This follows the European Directive on Waste Electrical and Electronic Equipment (European Commission, 2019). These ideas are often expressed in terms of the Circular Economy where the ideal scenario is zero waste supported by renewable energy sources for new product development.

Table 1: Fundamental views of ethics origins with a vernacular interpretation.

Concept	Reference	Vernacular interpretation
The golden rule	Mintz, 2012	Not in my backyard
Scandalous behaviour	Bustard, 2018	The pub test
Good citizenship	Punzi, 2017	Common good versus greater good
Pragmatism	Nair & Bulleit, 2019	Compromise and satisficing

Some of the major discussion points in Module 3 focus on the acquisition, storage, ownership, use and sale of big data sets. Clearly, infrastructure planning and product development can be based on survey data collected with or without the permission of the people. The location of these storage facilities in remote regions emphasises the high speed communication demands for access, backup and cyber security.

Module 4 explores at the future of biomedical interventions and the opportunities now available through the National Disability Insurance Scheme (NDIS) for independent living. Future developments and retro-fits in buildings, transport, etc., may require alternative technologies to accommodate an increasing diversity of human capabilities. The use of exoskeletons for super-human strength and endurance changes the nature of some work. This has ethical implications for the labour force and the physical and emotional health of the human workforce.

Module 5 asks students to watch John Cleese's "stupid people" video (Cleese, 2019) based on the paper published by Dunning et al (2003). This leads to a discussion of addressing an audience in terms that they might understand, and that each individual perhaps should trust the words of experts who are more knowledgeable than themselves in addressing a particular technical or other question. From this base, the idea of false or misleading advertising is issued as a warning to premature release of sales brochures and reaching to the ethics of crowd funding of products. The challenge of whistle blowing is also discussed.

The final module (Module 6) reviews the possibilities and promises of AI and machine learning in the future, particularly as it applies to engineering design, manufacture and use. This includes the social implications of changing work requirements and the review of technological implications aimed at ensuring that satisfying work continues to be available for the skilled and unskilled labour force.

The course assessment is based on weekly feedback sheets, which contribute to a personal Ethics Portfolio. As an on-line course, students interact with the course material through blackboard (course content, videos, readings, safe assign, teams, forms, etc.), with weekly scheduled classroom sessions for discussion.

The first informal feedback from students has been anecdotal during on-line classroom sessions and chats in the on-line chat room. Several students reported immediate use in their workplace of the materials and knowledge gained in the course. The formal feedback is expected to be received at the end of October 2019. Qualitative and quantitative responses will be discussed during the AAEE conference presentation in December 2019.

Conclusions

Student engagement is the well-known 'secret' to student learning. These two courses have been designed to introduce the new engineering paradigm into which the next batch of graduates will work. While not highly technical in nature, the fundamental concepts of AI, machine learning, circular economy, life cycle analysis, etc., are introduced through videos, lectures, MS forms and other methods of enhanced student engagement. The result for high achieving students is an ethics toolkit designed to equip them for a very unpredictable future.

These two courses, following the motivational strategy of Bustard (2018), are relevant to all engineering disciplines. Students work in their disciplines with weekly worksheets. The result is that the relevance is not lost in abstract ideas of ethics - although the basics are still important. The student engagement has been promising, and results will be available for discussion at the AAEE conference in December 2019.

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