# History and Philosophy of Engineering

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## CONTEXT

Most undergraduate engineering units of study tend to focus on the development of technical skills and knowledge, coupled with the ability to apply these skills and knowledge. Engineers also need to be able to critically reflect on the nature of the work they do, using aspects of philosophical enquiry to examine and analyse the nature and impact of their work. The form of this philosophical enquiry can be very broad, and may include aspects such as; ethics, sustainability, risk, aesthetics, socio-political factors, methodology and critical thinking.

## PURPOSE

To provide a learning opportunity and environment for students interested in a holistic overview of engineering; what it means to be an engineer, how engineers interact with society, how the nature of engineering has changed over time and to help create an awareness of the need for engineers to effectively use critical thinking skills and techniques when examining problems and designing engineered solutions.

## APPROACH

A first-year level Unit of Study (UoS) (ENGG1000 History and Philosophy of Engineering) was developed in 2013 and has been delivered every semester since 2014. The unit is aimed at multi-disciplinary engineering students who are interested in gaining a broad overview of the history, nature, and philosophy of engineering. The UoS is delivered by a single facilitator, in a small, intimate learning environment. A traditional lecture/tutorial based teaching model is not utilised; rather every session is delivered with flexibility, driven strongly by student input. Class discussion of ideas and concepts related to the syllabus form the core basis for learning; with the direction of discussion and material covered often led by students. Students also have input into the nature and structure of assessment tasks, and corresponding assessment criteria.

## RESULTS

Student feedback was obtained via formal Unit of Study Surveys (USS) and informal discussions with students, plus unsolicited emails from students. The UoS receives very favourable responses in the USS and has been awarded faculty teaching commendations. The students find it interesting, engaging and a welcomed change to their more technically focussed subjects.

## CONCLUSIONS

The small class size led to a positive discussion based learning environment and students find the course interesting, primarily due to the nature of the subject matter and the learning environment. Students gain an increased awareness of various philosophical aspects of engineering, more understanding of the evolving role of engineers in society, and develop their own personal philosophy of engineering.

## KEYWORDS

History, Philosophy, Engineering, Critical Thinking

# Introduction and background

Most undergraduate engineering units of study tend to focus on the development of technical skills and knowledge, coupled with the ability to apply these skills and knowledge to relevant problems. However, it is also important that engineers can critically reflect on the nature, impact and significance of the work they do, using elements of philosophical enquiry and critical thinking skills; to ensure their work is aligned with the needs, expectations and requirements of society. Due to the diverse, holistic nature of engineering applications, the form of this philosophical enquiry will be broad, and may include aspects such as ethics, sustainability, risk, aesthetics, socio-political factors, methodology, critical thinking, the epistemology of engineering plus others.

This paper discusses and describes a unit of study (ENGG1000 History and Philosophy of Engineering) developed and delivered in the Faulty of Engineering and Information Technologies at the University of Sydney by the author, over the past four years. ENGG1000 is a first-year level free elective aimed at engineering students who are interested in gaining a broad overview of the history, nature, and philosophy of engineering. Enrolment levels are approximately 20 per semester, with most students being in their final year of undergraduate study and from all engineering disciplines within the Faculty. Students mostly have a genuine interest in the subject matter and engage with the material, but there are also always a few that take the course to enable full enrolment load or for other various reasons.

The aim of the paper is to introduce the unit of study and provide background/context and reasoning for the importance of the subject matter, in the context of engineering curriculum. It is hypothesised that students achieve positive pedagogical outcomes, such as improved critical thinking skills, greater levels of engaged enquiry and an awareness of the role engineers play in shaping society.

## Philosophy of engineering

Philosophy of engineering is a recent area of study that is similar in many ways to philosophy of science, but much less mature in its development. Applying philosophical principles to engineering is not new and engineers often do so without realising, but creating a greater awareness of philosophical methodology in engineering students through formal study is less common. There is much scope for philosophy to help inform the practice of engineering, and for engineering to inform and raise philosophical questions. Gaining greater understanding of philosophical concepts and techniques can be of advantage to engineers dealing with complex problems; through the methods of conceptual clarification, critical thinking and clear argument (McCarthy, 2007).

Merging philosophy and engineering together can be difficult, primarily when analysing the conception of knowledge, with knowledge generated by engineering normally differing from knowledge generated by philosophical reflection. Large scale engineering projects contain a vast amount of knowledge, generated by many teams and the resultant knowledge is held by organisations, rather than by individuals (McCarthy, 2007). Much of the knowledge generated by engineering projects can also not be verified by scientific theories, due to the imprecise nature of many engineering activities. It is therefore of value to explore and analyse the methodology of engineering, in order to gain a greater philosophical understanding of the nature of engineering (Bulleit, Schmidt, Alvi, Nelson, & Rodriguez-Nikl, 2015).

## Engaged and enquiring minds

A general move towards online, flipped and blended learning strategies in engineering education has led to students' requiring a greater self-motivation to learn and manage their own learning activities. First year students especially find this more difficult as their learning prior to University entrance is typically more teacher oriented. Successful latter year

engineering students have generally developed more effective personal learning strategies, and perhaps also a stronger ‘enquiring’ mind-set.

Engineering students’ exhibiting greater enquiring mind tendencies are typically more motivated to study, seek information through research (most often online) and develop a greater understanding of subject matter and the context in which is relates to or is applied, and generally adopt a ‘deep’ learning approach. From the author’s experience as an engineering educator, a minority of engineering students exhibit strong ‘enquiring mind’ tendencies.

In the current global environment, for a graduate engineer to be of increased value and use to an organisation, the possession of an enquiring mind is a valuable attribute, and should lead to better, more thorough and original engineering. Engineers that exhibit attributes of an enquiring mind should be more creative, innovative and thorough in engineering practice.

> *"The enquiring mind of engineers - 'how can I do it better, faster, safer' - has enriched human life on so many levels."* (Alexander, 2016)

Developing strong student engagement is a common aim of educators, with an expectation that students who are engaged in their learning will comprehend material faster and with ‘deeper’ understanding. Engaged students should also develop stronger foundations for life-long learning, a trait that is especially relevant to engineering students expected to undertake a life time of ongoing professional development.

Increased student engagement in learning should lead to a faster development of attributes related to an enquiring mind, as the students move towards deeper learning and understanding of the subject matter.

Another positive method to help develop a stronger sense of ownership and engagement with students is to actively involve them in the formation of assessment activities and corresponding assessment criteria (within reason and with limitations).

Most engineering courses delivered at University level do not actively or explicitly incorporate elements of philosophical enquiry, but rather are focused on the development of technical knowledge, skills and understanding. Encouraging students to actively analyse their knowledge and understanding, with questions such as; how they obtain knowledge? where did it come from? is it true? how do I know it’s true? can I improve/expand on this knowledge? can I apply it to different contexts? etc. helps foster the development of an enquiring mind, aiding these students to go beyond the ‘average’ engineering student’s level of knowledge and understanding.

## Critical thinking skills

Engineering students often lack critical thinking skills, or the ability to think critically *about* engineering, not just *within* engineering (Claris & Riley, 2012). Critical thinking skills and techniques are of vital importance for successful engineers, the ability to critically analyse information, processes and knowledge leads to more informed decision making, and corresponding beneficial outcomes to society.

The development of strong critical thinking skills in engineering students should also lead to higher levels of engagement and philosophical enquiry.

## Epistemology of engineering

Epistemology of engineering has changed over time, from ancient observers and experimenters, through the master and apprentice model and eventually to modern formal engineering education based on scientific knowledge and methods. Different students learn in differing ways, and creating an awareness of one’s own learning strengths and weaknesses through reflective learning is an important skill for engineering students to obtain, leading to more effective continual professional development.

A current challenge for engineering educators is to create a knowledgeable generation of engineers, who have the skills and knowledge beyond those presented in traditional engineering curriculum (Hamzah, Ismail, & Isa, 2012).

### Flexible, intimate learning environment

Smaller, more personal learning environments should have a positive impact on student engagement levels, provided the subject matter is interesting, relevant and engaging. Active contribution to discussions by students gives them a greater sense of involvement, and coupled with the ability to guide the discussion's direction, an increased sense of personal ownership of their own learning. When used in this way successfully, these class-wide discussions can lead to greater student engagement and help in the formation of philosophical enquiry.

### Engineers and society

Interaction between human society and engineers has helped develop and guide the advancement of engineering technology and humans; with society posing problems for engineers to solve, and engineers developing new technology that changed the course of human history, helping shape the world we live in now. This interaction is vitally important for society to continue to develop in a sustained manner.

### Historical changes in the nature of engineering

Many engineering students have an interest in the history of engineering and there is an enormous amount of information that exists. By examining the nature of engineering 'breakthroughs' over time and the subsequent impact on society, students gain an improved understanding of the potential impacts of their own engineering work.

The changing perception of society's views of engineers is also of interest, as throughout history the 'place' of engineers in society has varied. As we head towards an era of increased automation, the engineer is yet again placed in the situation of potentially creating large impacts on society, both positive and negative. Examining historical engineering processes, events and technologies aids engineering students to appreciate the multiplicity of causes and effects that are involved in the discipline, plus encourages students to ask how and why something did or did not happen, and to develop their own personal perspectives on 'how and why' (Dias, 2014).

The world is on the cusp of another great industrial revolution, the age of oil and coal is coming to an end, and increased use of automation will likely change the very nature of work for a large proportion of society, and have potentially huge impacts on the world. Engineers are very much responsible for these changes and need to be aware of the ethical and social implications of decisions they make, and impacts of engineering they perform.

## Implementation

A traditional lecture/tutorial based teaching model is not utilised in this unit; rather every session is delivered with flexibility, driven strongly by student input. Class discussion of ideas and concepts related to the syllabus form the core basis for learning activities; with the direction of discussion often led by students. Students also have input into the nature and structure of assessment tasks, and corresponding assessment criteria.

### Unit content/syllabus

The unit is delivered every semester and the general course structure is listed below:

1. Introduction, what is engineering?
2. History of engineering 1 (prehistory – romans)

3. Methodology and philosophy of engineering
4. Engineering and society
5. History of engineering 2 (medieval – industrial revolution)
6. Epistemology of engineering and professional development
7. History of engineering 3 (1880-1950)
8. Socio-politics of engineering and technology
9. History of engineering 4 (1950-present)
10. Critical thinking skills
11. Engineering and society, the future?

This general structure has been developed based on student feedback and class interaction; students always have strong interest in more discussion of the historical aspects of engineering, and those sessions can be hard to keep to schedule. A strong focus has been kept on course components that are related to the development of skills relevant to critical thinking and engaged philosophical enquiry; skills that should lead to an increased development of an enquiring mind.

The exact weekly content does vary somewhat, based on student interest and the extent, content and direction of classroom discussion. Topics of discussion that require further investigation are noted and taken to online forums for further investigation and discussion.

## Assessment activities

*Assessment tasks*

There are currently six assessable tasks/activities in the unit:

1. Oral presentation
2. Written report
3. Online multimedia blog
4. Quiz
5. Active class participation
6. Active online class participation

The oral presentation involves short presentations to the class of a significant engineering event or breakthrough, and discussion of the impact of the event/breakthrough on society.

The written report task varies based on students' ideas and proposals, generally there is a focus on technological breakthroughs, but some students explore the more philosophical aspects of the unit material.

The online multimedia task is well received by most students, as it allows them to utilise a large variety of sources of information and material, generally focusing on the evolution of a historical engineering technology/product and the subsequent impact on society. Some students have got very engaged in this activity and created over 40 posts during eight weeks. Other students engage with individual blogs by adding comments to posts.

The quiz is an in class short answer mini exam that assesses the students' understanding of the unit material and their ability to demonstrate and use philosophical concepts introduced in the unit.

The last component of assessment is class participation, both physically in class and also in an online learning environment (Blackboard LMS).

*Student contribution to assessment task details/criteria*

A popular feature of the unit is the ability of students to have active involvement in the development of the actual assessment tasks and grading criteria (within reason). Students are free to suggest the nature of topics for the report and blog, and as a class wide group determine many aspects of the grading criteria (within reason).

# Student reception and feedback

## USS Results

Over the seven instances that the unit has been delivered, the overall student satisfaction (as obtained through the Unit of Study Survey process has averaged 4.4/5.0). The unit has received multiple Faculty commendations.

In answer to the question “What have been the best aspects of this unit of study?”, (via the formal Unit of Study Survey process) students’ comments included:

> *“Engagement in classes. While tangents that occur in class can lead to us falling behind schedule, they are extremely interesting and really lead to challenging my perceptions about what it means to be an engineer - and what my responsibilities will be, especially when relating history and philosophy to major engineering projects throughout the past.”*
>
> *“This unit of study is one of the best ones that I have come across. The quality of teaching was spot on. This unit should be added as one of the core units. Everything about this unit was excellent and interesting.”*
>
> *“This was a very unique uos. Rod's units have always been different in a good way. This class was more of a conversation between everyone rather than Rod teaching. This was very enjoyable, and I wish we could have had more classes.”*
>
> *“The most interesting unit I have had this semester. The overall purpose of the unit was clear and has changed the way I think about engineering within society.”*
>
> *“Overall, the course itself was enjoyable and very fascinating. Being able to understand the past and present of engineering is such a key aspect to the success of future engineers.”*
>
> *“Open forum discussion was a great change from the normal unit. It has helped me develop skills that aren't really taught by any other subject”*
>
> *“It's a very interesting course and encourages me to use my own research skills to supplement what is learnt in class. It's very student-driven, and no maths, which is a nice change... The assessment tasks are also very enjoyable, and I like that they are so self-driven and you can do them on pretty much whatever you want. The format and small class sizes are also really good.”*
>
> *“I really enjoyed it. I didn't think I would, but I think it's going to help me be a better engineer.”*

Students have also occasionally provided unsolicited feedback via email, such as:

> *“…would like to say I miss History and Philosophy a lot. It was hands down the best subject I've done in my time at Sydney University.”*

In semester 2 2017, one student has returned from the previous semester to attend many of the sessions out of their own interest.

This year, two students that completed the unit have proposed and undertaken final year thesis projects with the author, related to engineering ethics. They attributed their interest in this field of research to having previously completed the unit of study.

Informal discussion sessions with the students indicate that the students find the course interesting and enjoyable, very different to their regular courses, and engaging - through both the nature of the subject matter and delivery of content. Students appreciate the flexibility in the course structure and the positive reception/incorporation of their ideas/thoughts into the course content and direction.

Student dissatisfaction does occur but is minimal and normally relates to face to face teaching hours being insufficient (majority of class does not want to increase the hours) and the subject of assessment tasks being too similar. Students were recently given greater freedom to generate their own assessment tasks (within reason) and a small number do take this opportunity to negotiate different tasks.

# Discussion

Encouraging the development of an enquiring mind aids students' engagement and levels of self-efficacy, by enabling them to obtain a deeper level of learning and understanding. (Patterson, Campbell, Busch-Vishniac, & Guillaume, 2011) Students are also more likely to gain a positive attitude towards learning and increased self-confidence (Riegle-Crumb et al., 2015) and are expected to have developed the basis for fundamental enquiry based competencies, which should aid them in future professional careers and improve their own agency and responsibility (Terkowsky, Haertel, & Bielski, 2014).

Informing students about concepts related to the epistemology of engineering helps them critically reflect on their own learning style, and to identify their personal strengths and weaknesses, which aids their continual ongoing professional development.

Discussing the historical development of engineering as a profession helps encourage development of an enquiring mind, as students generally gain interest in historical engineering events and undertake independent research.

Much of the unit's assessment activities revolve around the interaction between engineers and society, and how engineers have a very large and crucial role in the development and progression of society. Reinforcing this understanding in engineering students will help make them a more valuable member of society, and help align them with expectations of society.

Small class sizes foster an increased sense of involvement in students, normally leading to improved student engagement. Class wide discussions have proven very effective in generating student interest, and the multidisciplinary nature of the student cohort leads to an improved understanding of the more holistic and diverse nature of engineering. Active learning activities like effective class debate and discussion leads to more engaged students with stronger critical thinking skills (Hamouda & Tarlochan, 2015).

The difference between online and in class engagement is evident; students that may have difficulties speaking in class are often more active in the online environment, and the use of online discussion enables students to provide references and links etc. Students are actively encouraged early on to initiate their own discussion threads, with varying levels of success; some students will only ever reply to existing threads, whilst others engage an enquiring mind-set and actively seek new topics and points of interest to discuss.

The unit is not without issues, predominantly that by encouraging active class wide student led discussion it can be difficult to keep the unit on schedule; often active and lively discussions need to be stopped and taken online due to in-class time constraints, which often leads to students then becoming dis-engaged with the topic of discussion.

The unit tends to start with a more guided form of enquiry, with the unit facilitator posing questions and normally initiating/leading discussions earlier in the semester, with the aim of informing students about concepts and processes involved in philosophical enquiry. Students are then provided with less guidance and encouraged to form a more open style of enquiry, with the aim of improving their own self-led enquiry skills.

# Conclusion

### An engaged, philosophically enquiring mind

This paper provides a background and overview of a new unit of study related to the study of history and philosophy of engineering, outlined the general aims and unit structure, plus the expected and observed learning outcomes.

Small class sizes led to a positive discussion based learning environment and students find the course interesting and engaging, primarily due to the nature of the subject matter and the learning environment.

Students' completing the unit gain; a greater awareness of the role of engineers in society, improved skills and ability in philosophical enquiry, stronger critical thinking skills and greater development of an enquiring mind-set. These outcomes will enable students to become better engineers of more value to society, with the ability to greater inform themselves of impacts and implications of engineering projects/technologies, and to apply techniques of philosophical enquiry to make better decisions and create better products for the benefit of humankind. Elements of the unit could be applied to many other engineering units of study, specifically areas such as engaged enquiry and critical thinking and

It is the author's intention to undertake a scholarly longitudinal investigation of the learning outcomes related to this unit, in particular the concept of the encouragement and development of an enquiring mind-set in students, and whether it can lead to the creation of 'better' engineers for society.

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