UNIVERSITY BREADTH SUBJECT AS AN ENTRY TO CHEMICAL ENGINEERING

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INTRODUCTION

Breadth in a tertiary degree allows students to study beyond their core discipline, enabling students to explore other interests and be exposed to disciplines they have not previously investigated. A breadth subject permits students to formally incorporate such activity into their degrees, which is generally designed to encourage and promote multidisciplinary learning to students by attracting a cohort from a wide range of disciplines.[1,2] The main objective of a breadth subject is to broaden students' interests and ideas, as well as develop skills outside of their core discipline, making students more well-rounded graduates upon the completion of their degrees.

Breadth subjects can also be used to attract students to a discipline they had not previously considered and can be used as a recruitment tool for disenfranchised students looking to change their degree major. The breadth subject described here was used for both purposes, as a way of introducing engineering concepts to non-engineering students and to promote chemical engineering as a degree choice to students from other disciplines. This investigation reports on the design of this breadth subject to generate interest in chemical engineering among non-engineers and to evaluate the success of this breadth strategy to attract atypical students to the discipline. To achieve this objective, this breadth subject demonstrated the outcomes of chemical engineering practices around the core topic of energy from a sustainability and equitable perspective.[3] The focus was on highlighting to non-engineering students how the discipline provides solutions to energy challenges facing societies. To entice students, the subject activities and outcomes were designed so students developed real-world solutions to specific energy problems, which appealed to those students who are passionate about driving change in society.

The engineering degree at this major Australian university is a master's, and therefore the inclusion of an engineering-focused breadth subject during a bachelor's degree is ideally placed in the course to introduce students to engineering concepts. The breadth subject then leads into pathways for students to undertake introductory chemical engineering subjects, as well as mathematics and chemistry, that will make them eligible for entry to the chemical engineering masters program. The subject was called "Equitable and Sustainable Energy Futures" and promoted to bachelor's students, irrespective of their degree. To the best of the author's knowledge, this study presents the first use of a breadth subject as a vehicle to attract undergraduate students to engineering. Hence, the breadth subject pedagogy approach is presented, along with the subject structure and assessments, focusing on how the subject was tailored to avoid high-order mathematics that may intimidate non-science discipline students. The outcome of the subject is also reported in terms of quality of the student work in the form of student grades as well as the success of enticing students to chemical engineering. The outcome is a viable engineering-focused breadth subject that can act as an entry pathway to an engineering master's degree.

LITERATURE REVIEW

There is a niche field of chemical engineering education focused on educating non-engineering professionals. The purpose is to enable those students to understand engineering concepts and principles to better converse with chemical engineers and comprehend engineering projects. As such, these courses generally avoid detailed theory and mathematics, rather focusing on broader concepts about what a chemical engineer does and how engineering achieves outcomes.

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These courses have become successful, with professional engineering organizations offering them in a variety of short formats.[4,5] However, these courses' aim is to better educate people working alongside chemical engineers rather than as a form of breadth or as a pathway to an engineering degree. To the best of the author's knowledge, these courses have not been incorporated into a tertiary degree.

Many universities have entry-level engineering courses that introduce potential students to the various disciplines within engineering. However, these courses are designed for engineering pathway students who have already identified engineering as a possible major.[6-8] There are few courses available for non-engineering students to explore engineering's potential. Those courses that have been reported upon focus strongly on design, specifically multidisciplinary student design teams. The courses are aimed at presenting engineering design principles to non-engineering students to cross-train them for dealing with engineering students in a product design team. The outcome is a multidisciplinary design experience to all students, utilizing strengths from students from many disciplines, with the training providing students with skills to converse across a multidisciplinary team.[9-11] Generalization and flexibility in such courses have been identified as key criteria, especially at the earliest stages as specialization and details can intimidate potential students. Similarly, the design tasks are generally altruistic topics to be attractive to students. An example is using biologically inspired design to introduce engineering to arts students.[12]

Breadth subjects come in a wide range of forms and can cover many topics. The most successful breadth subjects are those that are focused on well-known issues and topics, so the students develop a deeper understanding while also learning about another discipline.[1,7] For example, a successful breadth subject based around humans and ecology is used to highlight human impact on the environment and therefore promote environmental science to students.[13] A similar strategy has been used by mathematics to attract students through a breadth subject focused on critical thinking with data analysis. This advertisement of critical thinking is attractive to students, and the subject demonstrates statistics through minimal mathematics.[14-15] Hence, it is not unknown to use breadth subjects to promote a discipline to potential students. However, there is no evidence in the literature of an engineering-focused breadth subject being used for this purpose.

BREADTH SUBJECT OBJECTIVES

The subject's objective is to introduce students to chemical engineering by discussing how energy shapes society, ranging from an individual to community and country perspective. The subject is contained in a 12-week semester course that is open to all bachelor's students in their first and second years. The students gain an understanding of what energy is, how energy is measured, and how energy is controlled and transformed, as well as how energy is transmitted through chemical engineering concepts. Students also discover the broad chemical engineering implications of energy in terms of technology, environmental impact, and engineering's central role in economic and social issues. Critically the subject teaches students that there is no shortage of energy, but a shortage of the environmental and social capacities for engineers to utilize the available energy, and this limitation can be overcome with chemical engineering solutions that have transformed different societies.

An important objective is for the students to develop future energy scenarios through engineering and the implications this has on different spatial scales (global, regional, national, community, and individual) as part of their critical thinking development. At the completion of the subject, students can use qualitative and basic quantitative engineering techniques to analyze energy resources, technology, usage, and requirements. Students can also evaluate and convey information about chemical engineering, specifically on fossil fuels, hydrogen, and energy transmission and consumption, as well as apply reasoning to evaluate engineering planning decisions. A component of the subject is non-engineering focused to ensure students gain a broader perspective of how engineering in energy systems is influenced by other disciplines. This includes a human geographic perspective (one lecture), which focuses on how energy shapes spaces such as cities and buildings. A business component (two weeks) discusses the fairness of energy decisions and how financial investments decisions on energy infrastructure and resources are made. In addition, a law component (one week) covers the legal and regulatory framework that supports and constrains energy projects, as well as the legal and environmental challenges involved in engineering energy projects.

INTENDED LEARNING OUTCOMES (ILOs)

As the breadth subject is an introduction aimed at non-engineers, the ILOs are based on the knowledge and comprehension categories of Bloom's cognitive domain.[16] The specific ILOs associated with the subject are as follows:

- Understand the role of energy in shaping society in various forms
- Gain a broad understanding of the key technological, engineering, environmental, and social issues that arise in energy usage and planning
- Be able to use basic quantitative and qualitative techniques to analyze, critically evaluate, and convey information about the nature of chemical engineering in energy generation, transmission, and consumption

- Demonstrate the ability to apply engineering reasoning to evaluate energy planning decisions

The objective of these ILOs is to ensure students gain an understanding of the importance engineering has in energy and understand how chemical engineers are associated with various aspects in energy planning. Students generally demonstrate a solid understanding about the role energy has in our society, including their own lives, and how broader technology, environmental, and social issues depend on engineering solutions. However, students generally struggle with the ability to analyze and evaluate energy planning and design solutions, in part because there are many potentially correct solutions and students have not yet developed the necessary critical reasoning skills, being early in their tertiary education.

SUBJECT STRUCTURE

The course was taught over a 12-week semester, with up to four contact hours per week in the form of a one-hour lecture, one to two hours of flipped class (time dependent on the activity), and a one-hour, in-class tutorial lead by a tutor. The general format is to use the lecture to introduce a related chemical engineering/energy topic, with the flipped class providing the students with the opportunity to explore aspects of the topic, and the weekly tutorial used to develop their quantitative and qualitative skills in support of the topic under consideration. The structural layout of the subject is provided in Table 1.

TABLE 1
Syllabus of the breadth subject focused on engineering – energy, covering the lecture and flipped classes for each week of semester.

Week	Lecture	Flipped Class
1	Introduction to Energy	History of energy and humanity development
2	Fossil Fuels	Environmental and social impact of fossil fuels
3	Transportation of Fuels	Shale gas industry and associated impacts
4	Renewable Energy	Conversion of biomass energy resources
5	Hydrogen	Pathways to accelerate the hydrogen economy
6	Storage of Energy	Potential and impact of chemical energy storage
7	Electricity	Base/peak load power generation and distribution
8	Energy on the Built Environment	Energy mapping of university campus(es)
9	Auditing of Energy Resources	Design of sustainable energy buildings
10	Finance of Energy Projects	Calculating the cost of energy
11	Equity of Energy Access	Financial incentives of engineering-energy projects
12	Energy's Legal Framework	Community acceptance of engineering projects

The lectures are based on a standard model of the educator presenting to a class utilizing lecture notes that highlight the key features of each topic, as well as using case studies to demonstrate the relevance of the theory to students' everyday experience. The flipped classes focus on the students engaging in team activities to evaluate and assess key issues around the weekly topic. Each student team chooses one aspect of the topic to consider, with each student team expected to report back to the cohort on the challenges and potential solutions to their specific topic. For example, in the Week 2 flipped class on the impact of fossil fuels, different team tasks are recognizing key engineering advancements that have allowed fossil fuels to be exploited, identifying technological solutions to minimize fossil fuels environmental impact (such as carbon capture), determining technological approaches to remediate the environmental damage of fossil fuels, and weighing the social benefits of inexpensive fossil fuels against their environmental impact. This learning experience then continues into the Week 3 flipped class on the shale gas industry, where student teams are tasked with identifying the key engineering criteria that have made shale gas an available energy source and describing how shale gas is transported and utilized. Students then compare the environmental impact of shale gas with other fossil fuels, determining engineering solutions to reduce the environmental footprint of the industry, as well as weighing the importance of energy security and independence of a country against the environmental impact.

The tutorials are all aligned with the weekly topic but are based around a central theme of developing an energy plan for the country Timor-Leste. This developing country has a range of energy and engineering issues that are strongly associated with improving its standard of living. Each weekly tutorial activity builds on the previous week's task, enabling students to gain a deep understanding of how engineering projects are developed and the interlinking of all energy topics. For example, the Week 3 activity is to analyze the natural gas processing facilities in Timor-Leste, undertaking simplified mass and energy balances of these facilities and identifying if there is enough production capacity to meet Timor-Leste's domestic requirements. This task builds on the energy resources and rankings determined in Weeks 1 and 2. Week 4 continues this by having the tutorial focus on shale gas resources, identify the key engineering technology to be used, and how these facilities can be integrated into local and/or national gas transmission grids. An important outcome of this tutorial approach is that students actively participate in addressing much needed real-world energy problems, which is attractive to many students from an altruism perspective. The activities of the weekly tutorials are provided in Table 2.

TABLE 2 **Tutorial activity for each week of the semester, based around the engineering energy development of Timor-Leste.**	
Week	**Tutorial activity**
1	Timor-Leste energy resources determination
2	Timor-Leste energy infrastructure ranking
3	Timor-Leste natural gas processing ability
4	Timor-Leste shale gas processing potential
5	Timor-Leste bioenergy resources ranking and technology choice
6	Timor-Leste chemical storage and hydropower environmental impact
7	Timor-Leste electricity management and capacity loading
8	Timor-Leste international port facility energy and fuel audit
9	Timor-Leste port facility sustainability designs
10	Economic evaluation of Timor-Leste energy engineering projects
11	Ranking of Timor-Leste energy engineering projects
12	International legal framework to support energy development projects in Timor-Leste

Tutorial Examples

The Week 2 tutorial requires the students to examine the energy infrastructure and associated resources across the thirteen municipalities of Timor-Leste and to rank the municipalities in order of best to least for energy infrastructure development projects. To do this, students must analyze energy documentation and maps of Timor-Leste that help them to identify where fossil fuel resources are based and the availability of renewable energy resources, as well as locate the existing engineering energy infrastructure crossing the country, such as energy pipelines. The students then use this information to establish a ranking in terms of best to least opportunity for each criterion. Tutors provide guidance on how to rank certain municipalities against each other, especially when some have similar infrastructure, as well as if the students are applying weighting towards one energy resource or infrastructure type over another. Interestingly, this tutorial outcome is heavily influenced by students' philosophical viewpoint on fossil fuels and renewable energy investment. The example provided in Table 3 is the outcome students generally achieve when considering all energy resources, coupled with population and infrastructure. However, for those students who

TABLE 3

Tutorial 2 example of ranking of Timor-Leste municipalities based on energy resources and infrastructure.

Municipality	Population (P)	Fossil Fuels (FF)	Solar Energy (SE)	Biomass (B)	Energy Infrastructure (EI)	$P \times FF \times SE \times B \times EI$	Ranking
Lautem	13	5	10	3	6	11700	9
Baucau	4	9	7	6	3	4536	7
Viqueque	12	1	8	2	9	1728	3
Manatuto	11	6	5	1	8	2640	5
Dili	1	13	6	12	2	1872	4
Aileu	7	10	11	8	12	73920	13
Manufahi	10	4	4	7	1	1120	1
Liquica	2	12	9	11	7	16632	11
Ermera	3	8	13	10	11	34320	12
Ainaro	6	2	12	9	10	12960	10
Bobonaro	5	11	2	5	5	2750	6
Cova Lima	8	3	3	4	4	1152	2
Oecusse	9	7	1	13	13	10647	8

were opposed to fossil fuels, the rankings were altered. This tutorial provided an opportunity to discuss with students how decisions are made on engineering projects and how technical feasibility and potential does not always equate with actual investment decisions.

Tutorial 8 is based on undertaking an energy audit and analysis of the new international deep-water port facility recently constructed in Dili, the capital of Timor-Leste. The students analyze the port's construction, start-up, and operational reports as well as financial auditing documents from international funding agencies to determine the various equipment onsite and the energy usage involved in its operation.[17] Students must then compare the equipment energy usage with the overall port's energy demand through a simple energy balance and determine why there is a discrepancy, with an example provided in Table 4. This discrepancy is associated with differences in seasonal operation (wet versus dry season), unlogged equipment usage, and significant unrecorded small device usage and efficiency losses due to connection to unreliable external infrastructure. Tutors provide instruction to students on how to analyze the respective reports, identifying key information and providing explanations, as students from different degrees often comprehend the reports differently. The subsequent audit is guided by the tutor, a PhD student who also helps the students analyze the key areas for energy usage and what components of the port could be improved to reduce energy usage (which is followed up in more detail in tutorial 9).

The students undertaking this tutorial get a strong understanding of the underlying engineering design of the port facility, as well as the specific design efficiencies in movement of cargo and freight (mass balance). However, they also get insight into the dependency of the port's operations on external infrastructure and how these engineering deficiencies produce energy wastage. This enables a discussion about what external infrastructure is needed to enable the port facility to operate more efficiently.

TABLE 4
Tutorial 8 example of the resulting energy auditing of the new international port facility in Dili.

Equipment	Energy (kWh)
Stevedoring	
Permanent Crane (x2)	8602
Rail-mounted Crane (x2)	14401.95
Portal Crane (x2)	442.5
Mobile Harbor Crane (x1)	1201.2
Control Room	492
Cargo Ship Fueling	40000 bbl
Tug Boat Fueling	25000 bbl
Cargo Storage	
Mobile Crane (x2)	122402.4
Refrigeration Units	7207.2
Truck Mounting Crane (x2)	1201.2
Quarantine Station	240
Truck Refueling (x2)	800 bbl
Harbor Master	
Control Tower	912
Office Building	58.56
Immigration Building	7200
Custom Building	9000
Administration	
Office Building	7800
Canteen	1171.2
Border Control	4804.8
Security	12000
Staff Cars	250 bbl

ASSESSMENTS

The breadth subject assessment tasks consisted of the following:

- Energy mapping and analysis essay (15% of final grade, due Week 3)
- Energy modelling essay (15% of final grade, due Week 7)
- Video presentation of a home energy audit (10% of final grade, due Week 10)
- Energy case study analysis essay (60% of final grade, due during the exam period)

There was no final exam for the subject, rather all assessments were essay based with one video presentation. The presence of no exam was a strategic choice to ensure the breadth subject would be attractive to students from disciplines with subjects that are more focused on essay and project work, e.g., arts and design degrees.

The energy mapping and modelling essays are focused on regions within the state of Victoria, Australia; specifically, the Mallee and the Gippsland regions, as both locations demonstrate developed communities that have an abundance of energy resources, renewables and fossil fuels, respectively. The choice of these locations was also to contrast with the tutorial problems on energy development in Timor-Leste, as students could easily compare the type of engineering infrastructure in the respective locations and see how this is reflected in the social-economic standards of the surrounding communities. An example of the student mapping outcomes is provided in Figure 1 for the Mallee region. The video presentation assessment is focused on the students doing a home energy audit of their dwelling (i.e., material and energy balance of their dwelling) to help students understand their own energy consumption and wastage, as well as identify practices and alternatives that enable energy savings. The purpose of this assessment is to translate their learnings from the subject to their everyday lives. This assessment is undertaken as a video recording to provide students with the experience of a presentation.

The major assessment task is an energy case study analysis, based on a specific municipality located in either the Mallee or Gippsland regions. As part of the case study, the student must determine, in detail, the energy demand of the municipality, the available energy resources, and the environmental impact of those energy resources. Students must also suggest alternative engineering technology that can be used to provide the energy demand as well as develop a plan for transitioning the municipality energy usage to more efficient engineering technology and describing how this will alter the social, economic, and environmental situation. As this is the major assessment, the students must demonstrate critical analysis skills in evaluating the energy situation and engineering required to improve the municipality.

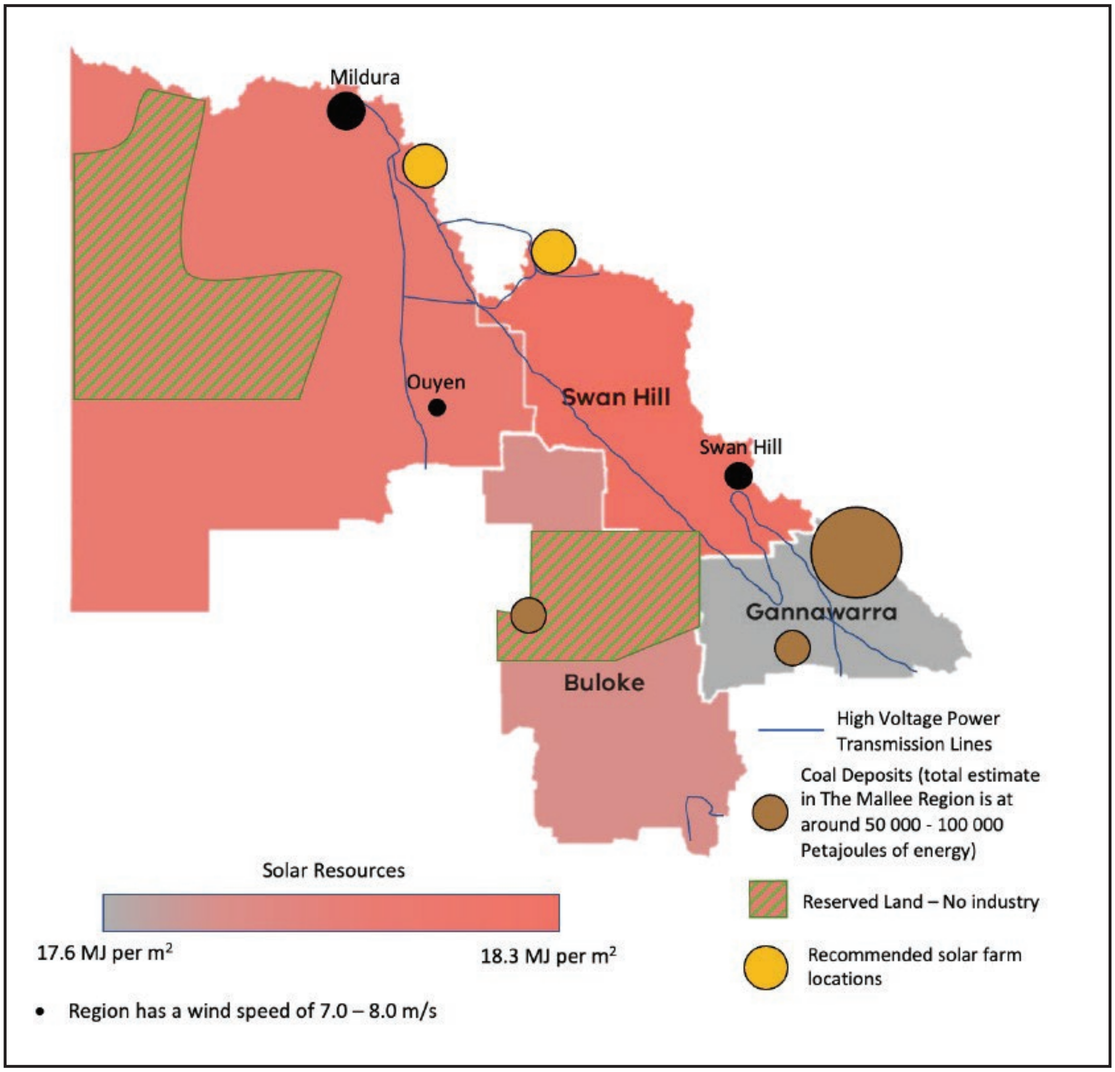

Figure 1. *An example of a student assessment of energy resources in the Mallee region and the ability to link renewable energy, taken from an average graded student assessment.*

RESULTS AND DISCUSSION

This dataset covered two years and consists of 86 students. The successful learning outcomes of the breadth subject were demonstrated by most of the student cohort performing well in all assessments and achieving high grades. To date, only three students have failed the breadth subject, all of which were associated with failing to submit two or more assessments and obtaining a zero grade, rather than the quality of their submitted work being unsatisfactory. The breakdown in the student cohort grades, based on their bachelor's degree, is provided in Figure 2. Interestingly, Bachelor of Arts students had on average the highest grade, while Bachelor of Science students' average grade was the lowest for the subject, with Bachelor of Design students achieving slightly higher grades than Commerce students. This difference between Arts and Science students is attributed to the nature of the assessment activities primarily being essay and critical thinking tasks. Arts students have considerably more experience in this form of assessment than Science students, who are familiar with descriptive and calculation-based exams. Hence, this is reflected in the grades, but it should be mentioned that the breadth subject purposely ignores calculation-based assessments so not to disadvantage Arts and Design students.

Determination of how many students eventually progressed to an engineering degree was difficult to evaluate. Rather, the subsequent subject choices of the student cohorts were monitored to identify those students who clearly had developed an interest in chemical engineering and were motivated to pursue this further.

Bachelor of Science students had the highest transition to chemical engineering related subjects at 93% (26 students), in part because many of those subjects are strongly associated with their science degree. This is expected, as the similarity between Science and Engineering students is clear, and the current science degree had already acted as an entry to the Engineering Master's program for over a decade. The Bachelor of Design students also increased their engagement in the STEM disciplines, with 45% (12 students) of this cohort enrolling in an additional mathematics subject that is not part of their core degree. However, only one student enrolled in additional chemical engineering subjects. Similarly, the Bachelor of Commerce students had a 45% (five students) enrollment in chemistry, though their additional enrollment in mathematics was lower at 20% (two students). Bachelor of Arts students unfortunately did not translate well into further engineering study, with only 5% (one student) identified as enrolling in an associated chemical engineering subject. This was attributed to the discipline of engineering being too different from arts for an immediate transition to be observed. As such, the breadth subject attracted students already in a science/technical focused program.

EVALUATION OF THE LEARNING APPROACH

The metrics of the performance of the breadth subject were obtained through the official student experience survey run by the University. The survey is generic to all degree subjects, with the evaluation of performance associated with the specific questions "Satisfied with the learning experience?" and "The study materials and resources of this subject were helpful in my learning?," with the scoring system ranging from 1 (strongly disagree) to 5 (strongly agree).

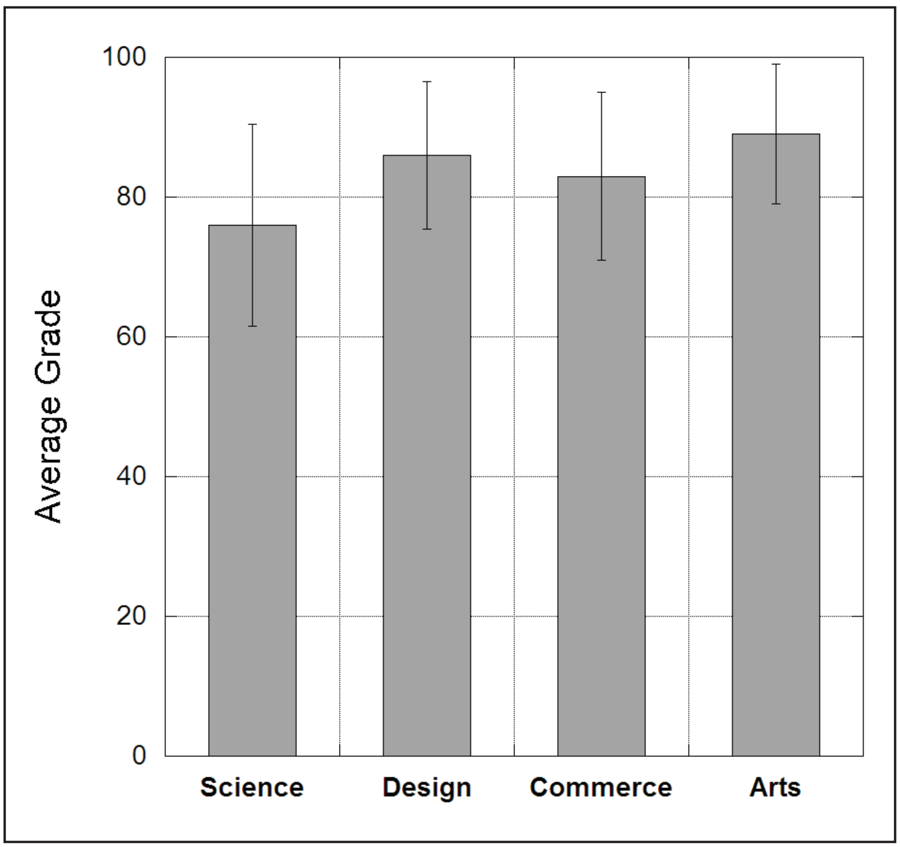

Figure 2. *Average grade of students undertaking the breadth subject, based on their bachelor's degree.*

The average score for both questions was 4.67 (out of 5), indicating a large proportion of the cohort found the breadth subject engaging and a rewarding learning experience. The average score for both questions across the entire Faculty of Engineering was 4 and 4.1, respectively. The positive learning experience of the subject was supported by the student comments in the official survey, which were strongly positive. Some student comments are as follows:

> "*Such an insightful course that have given me great consciousness of how real-world energy futures come to fruition*."

> "*This subject has been very well done, the assignments are engaging and the lectures very informative*."

> "*The assignments are the perfect balance of instruction and self guided learning*."

The subject also clearly improved student opinions of engineering role in society, as highlighted by this statement:

> "*Such an insightful course that have given me great consciousness of real-world engineering come to fruition*."

However, the workload of the subject was a concern for some students, as evident in the following comment:

> "*I was interested in the tutorial work, but simply did not have enough time to complete the tasks, so perhaps the scope of the tutorial work could be reduced to make completion achievable within the given time*."

The confidentiality of the survey prevented an analysis of the outcomes in terms of student disciplines areas.

CONCLUSIONS

The ability to promote chemical engineering to non-engineers and attract a wider cohort of students to the discipline is an important endeavor. The breadth subject presented here is a tool that has been used for that objective, with reasonable success. The connection between energy and engineering has been used to promote the potential of chemical engineering and importantly the role chemical engineering has in many of the critical issues facing the global community. Presenting learning activities that contrast the energy and engineering environment in developing and developed societies ensures strong engagement from students and achieves solid learning outcomes. The course was well received by students from a range of bachelor's degrees, with encouraging uptake of engineering-based subjects from science and design students. To conclude, the use of breadth as a mechanism to attract students on a science track to chemical engineering is a viable strategy.

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