Original Article

IJMEE

International Journal of Mechanical Engineering Education
2017, Vol. 45(1) 47–58
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DOI: 10.1177/0306419016674508
ijj.sagepub.com

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A unified first-year engineering design-based learning course

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Abstract

This paper describes an innovative engineering design of a first-year engineering course. The course is offered in the second semester of the academic year to students of different engineering disciplines such as mechanical, mechatronic, electrical, electronics, civil, environmental and manufacturing. The course incorporates a mix of techniques to help students better engage with the subject matter and with one another. A major part of the new course is the practical assessment component requiring students to apply physical, mathematical, mechanical and electrical concepts to real life engineering design problems. Three different engineering design modules were developed. Each module consists of an authentic engineering design problem which has been specially constructed in order to provide students with the opportunity to apply the basic engineering, maths and physics concepts they acquired during the first semester. Depending on the students intended engineering major, they choose one of the three engineering design modules. In order to best prepare students for the design project, they firstly do two small group assignment tasks on a particular engineering problem. This serves as the preparatory work for the engineering design module. The assignments are done in class time so as to promote full collaboration between students and instructors and to encourage the exchange of knowledge and ideas. The course aims to better equip students with workforce skills in problem solving and effective oral and written communication.

Keywords

Design, curriculum, first-year engineering

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Introduction

Various design-based learning methods have been introduced in many undergraduate engineering programs with the aim of exposing students early in their learning to problem analysis and good design practices. Such methods have also shown to help increase student engagement and to develop a more comprehensive appreciation for the different aspects of engineering.

Nowadays, engineering education needs to meet the requirements and needs of business and industry. This can be achieved by collaborating with the local industry to adopt real life engineering design problems. Such type of collaboration was implemented by capstone senior design projects. In the study reported by Odeh and Abu-Mulaweh,[1,2] senior mechanical engineering students applied engineering concepts in renewable energy. They designed and constructed various experimental apparatus which were then used by junior engineering students to help them understand the basic heat transfer processes, thermodynamics concepts, photovoltaics principles, and solar tracking technology.

Newman and Amir[3] reported that the integration of design into the engineering curriculum in aeronautics motivated and excited first-year students. Joyce et al.[4] introduced a group design and manufacturing module to mechanical engineering students which required them to build and test a paper-based exercise over a three-year period and made annual refinements to its design based on student feedback.

Heylen et al.[5] redesigned their first-year engineering curriculum to be more project based, so that students were introduced to real engineering practice and teamwork from the first semester. Assignments became more complex so that students could develop skills in using a systematic approach to problem solving and engineering design.

Mehalik and Schunn[6] and Puente et al.[7] conducted an extensive literature survey on design-based learning in higher engineering education and concluded that while a design-based learning approach did not necessarily lead to good design practice, at least preparatory activities for good design practices were improved. Students were better prepared in how to frame a design problem, how to use interactive/iterative design methodology, and how to build a normative model.

Froyd et al.[8] developed a first-year engineering curriculum that is based on different design specifications and outcomes: predict performance before construction, connecting engineering to local society, apply the learned science and mathematics concepts to the requested design, transfer learning from concept base course to project based activities. Engineering students were able to learn these specifications and outcomes through conducting five design projects and prototypes in the first-year curriculum. This work showed that several small projects instead of a single semester long project will allow the students to apply and explore the design process multiple times.

Heeny and Foster[9] wanted to promote sustainable development as an integral part of design so they introduced a compulsory sustainability development unit into a first-year engineering science curriculum. A key challenge was encouraging students to follow an iterative design process which would better equip them with transferable skills to "make and defend design decisions."

To improve student understanding of course content in chemical engineering, Jollands and Parthasarathy[10] developed a multi-project program from the sophomore to the senior year. New project topics related to sustainability were proposed each year and students worked in groups to choose the optimum design based on key criteria.

In their study on design-based learning, Chua et al.[11] found that when combined with appropriate tools such as mind-maps, the use of analogies and the use of round-table discussions, student engagement in the learning process increased and their level of knowledge applied during project implementation was higher.

In today's global business world, it is important that students develop skills and knowledge that is readily transferable to other countries and cultures. With this aim, Maldonado et al.[12] implemented a first-year design project, where aerospace engineering students worked in multicultural teams over a two-week period to design, build and flight test a model aircraft.

Giralt et al.[13] reported a study on a first-year engineering design project that involves two-way integration of subject material; horizontally with first-year subjects and vertically with a fourth-year project management subject. First-year engineering students worked on their project design in teams led by a fourth-year student acting as project manager. It was found that exposure to this type of collaboration between two levels of students provided useful practical experience and also helped develop a more student-centred curriculum.

Gaining and keeping students' attention and interest are just two critical factors in running a successful first-year engineering curriculum where success means good pass rate and students continuing on to second year. The above examples of innovation in engineering courses have highlighted the benefit of using practical team-based design projects early in a first-year student's exposure to university.

Another recognised motivator for university students to learn the subject material is assessment. When the assessment is carefully designed around practical learning outcomes and is fully integrated into the subject, students have been found to be more appreciative of the subject and gain a better understanding of it. Boud and Falchikov[14] and Ross et al.[15] described the results of numerous assessment developments they made over several years in order to attain authentic learning and assessment experiences for students. Feedback from students was that they enjoyed the course more and believed the assessment tasks led them to have longer term memory and better understanding of topics rather than just rote learn for exams.

This paper introduces a new first-year engineering curriculum. The course is offered in the second semester of the academic year to students of different types of engineering disciplines such as: mechanical, mechatronic, electrical, electronics, civil, environmental, and manufacturing. The core part of this course is the design project modules where students from these engineering disciplines can apply physical, mathematical, mechanical and electrical concepts to real life preliminary designs.

Course details and structure

The proposed course is part of the new curriculum developed in 2015 at the Sydney Institute of Business and Technology (SIBT). The Institute is a tertiary college that offers students an entrance pathway to SIBT's Australian partner universities. Students who successfully complete the first-year or part of the second-year program offered by SIBT can then transition directly into the second-year program at one of the Australian partner universities. The majority of students are from overseas and English is not their first language. They are required to have IELTS level 5.5.

Historically, SIBT's major partner was Macquarie University but as competition for student enrolments increases, SIBT has sought relationships with other major Australian universities, namely Latrobe University and Western Sydney University. Consequently, the first-year engineering curriculum needed to be modified to satisfy the requirements of each partner.

The redesign needed to accommodate and serve the different course structures for the different engineering disciplines of electronics, electrical, telecommunication, mechatronics, and mechanical. To reflect this, the course name was changed from electromechanics to Fundamentals of Engineering Studies. Lectures focused on the areas of mechanics and electrical circuits.

Educational design enhancements to the course included:

- More practical models, online simulations, short videos and real life examples to introduce, explain and demonstrate key concepts.
- A Welcome video and demonstration videos to explain the key concepts covered in the first four weeks to assist students who enrol late.
- In-lecture use of Socrative to check for understanding of key points before moving on to the next topic.
- Online self-assessment.
- Pre-lecture material of specific discipline language to be encountered in the lecture.
- Options for students to provide anonymous online feedback throughout the semester.
- Opportunities for students to apply their knowledge to build models which other students then test and rate.

To maximise the opportunity to successfully complete the course, additional academic assistance and support is provided to students. There are weekly workshops in academic time management, goal setting, essay preparation, examination techniques, academic writing skills and maths. Students may also meet individually with Learning Advisors.

The core assessment tasks in the new curriculum consist of two preliminary design tasks which lead into the final design challenge. Students work in teams of four to devise their solution to an authentic engineering problem. The lecturer and tutor provide guidance to the teams.

The assignments are done in class time so as to promote full collaboration between students and lecturers/tutors and to encourage the exchange of knowledge and ideas.

In week 7 of the semester, students then choose one of the following practical engineering design modules based on their intended engineering major:

- Module I: mechanical, mechatronics, and manufacturing
- Module II: civil & environmental engineering
- Module III: electrical, electronics, computer, and renewable energy engineering

Time is allocated in the tutorials for students to work as a team on their design. Any encountered problems or queries are shared with the whole class in order to continually promote a collaborative learning environment.

An example of a professional engineering design report is provided. Students prepare a truncated version for their final project.

Fundamentals of engineering studies course and student outcomes

Upon successful completion of this course, the students will be able to:

1. Apply fundamental theories and concepts of mathematics, geometry, and physics to analyse and solve engineering problems.
2. Use basic principles of Engineering Mechanics – Statics to analyse and resolve the forces acting on a mechanical system.
3. Visualise physical configuration and illustrate mechanism of different engineering systems.
4. Identify electronic circuit components and variables and use circuit laws and theories to solve electrical and electronic circuit problems of low complexity.
5. Understand the commonality between problems in electrical and mechanical engineering for linear systems and modelling.
6. Apply theory to real life application and perform simple engineering designs.

The curriculum enables the following college signature capabilities:

1. Discipline Knowledge and Skills: student will have opportunity to apply the knowledge they acquired in physics, mathematics, mechanics, and electricity to the engineering designs and problems.
2. Communication Skills: students will learn how to present and report their designs and solution of the engineering problems in a professional style.
3. Critical Thinking Skills: the design project will allow students to improve their engineering sense and to approach engineering problems in different ways.
4. Team Work: a variety of in-class group work is designed to encourage students to improve their collaboration skills and to openly share and exchange knowledge with each other.

Engineering design modules

Three different engineering design modules were developed for different engineering disciplines:

- Module I: Mechanical, mechatronics, and manufacturing: Design a component of a robotic arm using lever principle.
- Module II: Civil & environmental engineering: Preliminary design of a truss bridge.
- Module III: Electrical, electronics, computer, and renewable energy engineering: Preliminary design of a residential solar power system.

Design teams are formed based on the abovementioned engineering disciplines. The design process that students are asked to follow is the one outlined by Bejan et al.[16] and Jaluria.[17] The first essential and basic feature of this process is the formulation of the problem statement. The formulation of the design problem statement involves determining the requirements of the system, the given parameters, the design variables, any limitations or constraints, and any additional considerations arising from safety, financial, environmental, or other concerns.

Module descriptions

Module I: Design a component of a robotic arm using lever principle (mechanical, mechatronics, and manufacturing)

A soft drink factory has a canning process with different types of robotic arms. At a certain stage of this process, a simple robotic arm similar to the schematic shown in Figure 1 is used to move a 350 ml soft drink can from the production line. The arm must be able to lift the can by applying a force on its end equals to ¼ the weight of that can. As a design engineer you are required to use the lever principle to setup *the robotic arm specifications* (arm length, arm force components and the driving motor power). In order to implement your design you need to search some information and make some assumption such as: lever arm length, can weight, motor speed, etc.

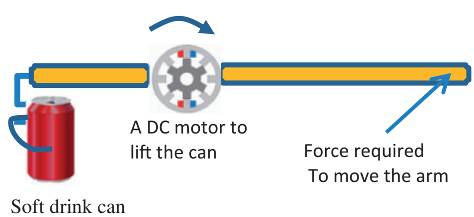

Figure 1. Simple robotic arm of canning process in a soft drink factory.

Module II: Preliminary design of a truss bridge (Civil & Environmental Engineering)

The local council in your city is required to connect two river banks by a truss bridge similar to the schematics shown in Figure 2. Two vehicles can cross the bridge at one time and the approximate distance between them is shown in the figure. The maximum mass of each vehicle will not exceed 500 kg (including the passengers). The cost of this project will depend on the number of joints in the truss structure. As an engineer, you must conduct preliminary design calculations to *determine what the minimum number of joints in this truss bridge can be*. In order to implement your design, you will need to make certain assumptions such as: the weight of the bridge, centre of mass of the bridge and the vehicles, number of supports to the bridge span, the strength of each truss member to resist tension or compression forces.

The council requires the bridge to be openable to allow for boat movement along the river as shown in Figure 3. You also need to calculate *the power of the motor gear system that will be required to be installed at each side of the bridge span*.

Module III: Preliminary design of a residential solar power system (electrical, electronics, computer, and renewable energy engineering)

The local council in your city requires a design for an off-grid solar power system for a house in a remote area. The design of this system will depend on the daily energy demand of a typical house. The core item of the solar power system is a photovoltaics panel of 175 W output in the residential application. In order to implement your

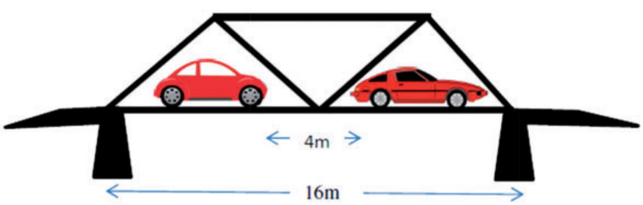

Figure 2. Bridge dimensions.

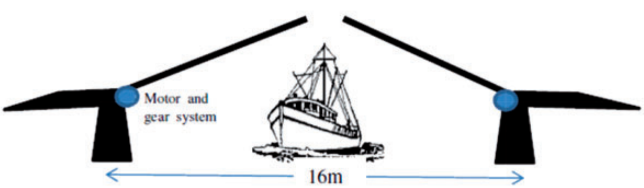

Figure 3. Bridge with a capability to open.

Figure 4. PV panel tilted frame.

design, you need to search some information and make some assumption such as: panel average power output and average energy demand of the house.

To orient the panel to the true north, you are required to design the support frame similar to the one in Figure 4 that can resist the force developed by wind speed of 40 km/h. Find the wind force and reaction at the support joints.

Student feedback

At the end of each semester, students are required to evaluate the course and to self-assess their performance in the course. This assessment is done through two surveys using "Socrative" application.

The success of the learning techniques used in the design based first-year engineering course was assessed via a student survey shown in Table 1. The questions address the unit content, unit materials, requested tasks and skills development. The results of this survey are presented in Figure 5. Overall student satisfaction with the curriculum in general was 88%. This result was verified by the survey results of teaching staff which include question about teaching techniques, rapport with students, learning environment and continuous feedback. The different questions showed consistency in the results and a high satisfaction level by students.

The student self-assessment questions are focused on the level of quality of the design, originality and their ability to communicate. The survey questions are in Table 2, and the results are shown in Figure 6. Combining students' responses "strongly agree" and "agree" to the questions, and gives an indication regarding the class fulfilment of the design project requirements. The results were 75% which is very close to the actual class average grade on the final report which was 71%.

Educational benefits

Feedback from the formal surveys that were given to the students to assess specific learning from these activities, indicates that students are pleased with the experience. The feedback from the students was very positive, and their performance on

Table 1. Course evaluation survey.

		Choose one		
1	The aims and objectives were clearly stated.	1	2	3
2	Expectations for success in this unit were made clear.	1	2	3
3	The unit was paced to allow me to understand the topics in depth.	1	2	3
4	In this unit, I learnt how to communicate effectively my understanding of the unit content to others.	1	2	3
5	Teaching sessions (e.g. Lectures, Tutorials, Lab sessions, etc.) were structured in ways that assisted my learning.	1	2	3
6	The learning activities (assessment tasks, in-class exercises, homework, etc.) were useful for building up my understanding.	1	2	3
7	By solving problems in this unit, I gained a better understanding of the unit content.	1	2	3
8	Alternative points of view were presented when appropriate to cover the content taught.	1	2	3
9	The teaching materials for this unit (handouts, unit outlines, workbooks, etc.) were helpful to my learning.	1	2	3
10	The textbook(s) was easy to read and understand.	1	2	3
11	The material covered in this unit was effective in helping me prepare for assessment tasks.	1	2	3
12	Assessment tasks were set at an appropriate level.	1	2	3
13	This unit included enough guidance on how to complete assessment tasks well.	1	2	3
14	I received timely feedback that assisted my learning.	1	2	3
15	The feedback given in this unit helped me address my weaknesses.	1	2	3
16	Overall I am satisfied with this unit.	1	2	3

Note: 1: agree, 2: neutral; 3: disagree.

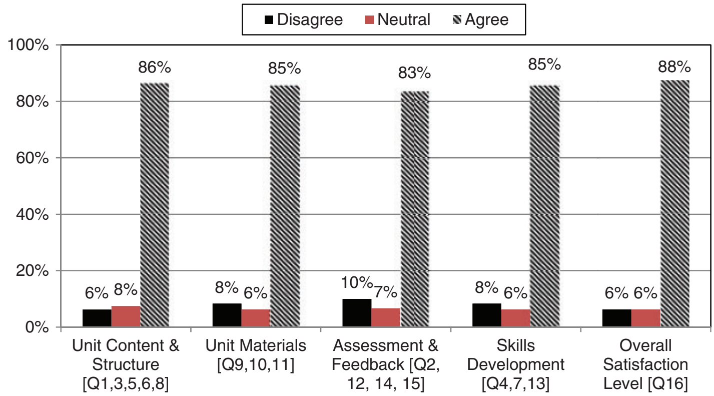

Figure 5. Course evaluation survey results.

Table 2. Self-assessment survey.

		Choose one			
1	My report is well organized and prepared.	A	B	C	D
2	I was creative in this project (proposed new ideas, calculation methods, etc.).	A	B	C	D
3	I used visualization tools (used some photos, diagrams, etc.) in your report.	A	B	C	D
4	I participated in the weekly discussion session.	A	B	C	D
5	I followed the design outlines and report requirements.	A	B	C	D
6	I showed all assumptions clearly.	A	B	C	D
7	I referred to at least two references and textbook in making assumptions and calculations.	A	B	C	D
8	I started working on the project in week 8 or before.	A	B	C	D
9	I didn't copy and paste from similar work and I understand how to design this project.	A	B	C	D
10	I now have a good understanding the design process and report preparation rules.	A	B	C	D

Note: A: strongly agree; B: agree; C: disagree; D: strongly disagree.

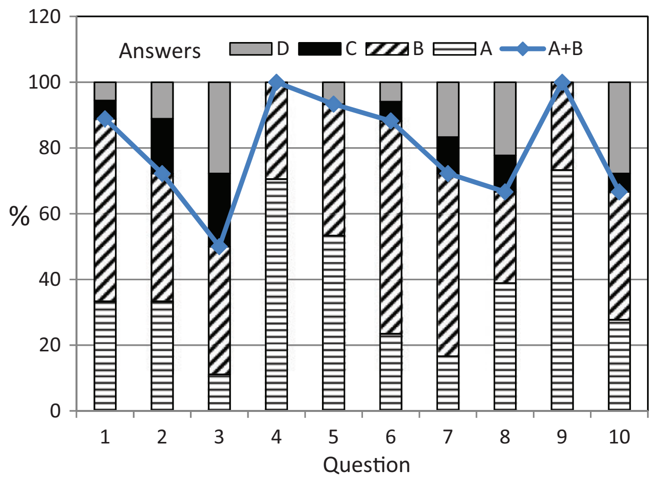

Figure 6. Self-assessment survey results.

in class exams has improved. These types of design projects required the students to search beyond the textbook and class notes in order to successfully complete these design projects. Moreover, some of these design projects gave the students the opportunity to work as a team.

Conclusion

An innovative engineering design experience is introduced in first-year engineering course. The core of this course is the engineering design modules where students from different engineering disciplines can apply physical, mathematical, mechanical and electrical concepts to real life preliminary designs.

Three engineering design modules were developed for the following engineering disciplines:

- Mechanical, mechatronics, and manufacturing
- Civil and environmental engineering
- Electrical, electronics, computer, and renewable energy engineering

Each module consists of an authentic engineering design problem which has been specially constructed in order to provide students with the opportunity to apply basic engineering, maths and physics concepts learned during the first semester. Students choose one of the three engineering design modules based on their intended engineering major.

Summative and formative feedback from students has been very positive. Participation in online self-assessment activities throughout the semester has been high which has contributed to improving students' understanding of key concepts and increasing their engagement overall with the course.

Grouping the students in the designed project based on their chosen discipline enhanced their engineering sense, their communication skills and more importantly introduced them to the kind of team work expected today's workplace.

Student feedback indicates that they now have a clearer understanding of what the different discipline areas of engineering involve which gives them more confidence when choosing their final major.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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