Project-Based Approach in a First-Year Engineering Course to Promote Project Management and Sustainability

https://doi.org/10.3991/ijep.v8i3.8573

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Abstract—To safeguard the environment and satisfy the energy needs of the present, without compromising the ability of future generations to do the same, sustainable energy development is urgently needed. This complex task is riddled with social, political, scientific, technical, and environmental challenges. Education is essential if we are to meet the energy demands of the world in the most sustainable manner available to us. Langara College offers a first-year engineering course that is meant to introduce students to engineering design and case studies, in addition to providing a brief glance on the history, ethics, and the different disciplines of engineering (APSC 1010). Using a project-based learning approach that promotes teamwork and research, this course uses a variety of instructional methods including lectures, class discussions, and guest appearances by experts in their fields. Introductions to technical concepts, such as soldering, 3D printing, and microcontrollers, are also addressed in this course. This paper demonstrates how this, or similar courses, are optimized to raise awareness of the sustainability issues this planet is facing. Learning outcomes are evaluated using an anonymous student survey which demonstrates how the students' project-management and presentation skills have improved.

Keywords—First-year engineering education, project-based learning, sustainability, project management.

1 Introduction

With the ever-increasing pressures of rising population, declining natural resources, and environmental changes, sustainability has become a critical and urgent need for all human activities. Sustainability can be defined as a condition in which natural and human systems survive and thrive together so that the consumption of natural resources does not have a hostile impact on the environment, various social conditions, and human health [1].

Engineers play an important role in the critical and multi-disciplinary shift to the development of a sustainable culture. National and international engineering organizations such as the World Federation of Engineering Organizations (WFEO) and

Engineers Canada highly encourage and mandate all engineers to be knowledgeable about the sustainable development technologies applicable to their work. Therefore, incorporating sustainability into engineering education is a vital strategy that many institutions have pursued [2]-[4]. However, due to the nature of this topic and the inexperience of undergraduate students, most of these efforts have been focused on graduate-level courses. Problem- and project-based learning provide an opportunity to raise the undergraduate engineering students' awareness of sustainability concepts, while improving their project-management skills [5].

Problem- and project-based learning are student-centered active learning approaches. They engage students in the learning process and result in increased motivation and confidence. Instead of teaching theories as done in traditional deductive pedagogies, students are asked to work on an open-ended real-life problem collaboratively [4]-[6]. There have been many successful attempts to engage problem- and project-based learning into engineering education [2].

Several benefits of problem- and project-based learning in engineering pedagogies have been reported in the literature [7]. Some of the benefits of hands-on collaborative engineering projects are outlined here:

- Promotes retention of theory applications, and improves overall learning
- Encourages students to pursue advanced degrees and careers in the engineering field
- Helps students in selecting their major
- Increases students' self-confidence
- Develops work ethics and understanding of safety
- Improves many soft skills such as:
  - Communication and conflict-resolution
  - Teamwork
  - Project and risk management
  - Time and stress management
  - Critical-thinking and problem-solving
  - Decision-making and leadership

Langara College, as one of BC's leading undergraduate institutions, offers the "Applied Science for Engineering" two-year diploma program (http://langara.ca/programs-and-courses/programs/applied-science-for-engineering/index.html) designed for students who wish to study university engineering, but either do not yet meet all the pre-requisites or need time to transition into the heavy workload that the study of engineering requires. Students gain a thorough background in mathematics and natural sciences, including laboratory practice, and technical communications. They are also introduced to Canadian engineering practice, history and social context, and the engineering principles of case study and design. This program was developed to provide a pathway for students, who might otherwise encounter significant challenges, to start pursuing a career in engineering. "APSC 1010: Engineering and Technology in Society," offered to first-term engineering students as a part of this program, is meant to introduce students to engineering design and case studies, in addition to providing a brief glance on the history, ethics, and the different disciplines of engineering (http://langara.ca/programs-and-courses/courses/APSC/1010.html). This paper is based on the author's experience teaching APSC 1010 during 2016-2017 and demonstrates how this, or similar courses are optimized to raise awareness of sustainability issues through project-based learning.

The rest of this paper is organized as follows: In section 2, course components, learning objectives, and lecture syllabus are discussed in detail. Section 3 focuses on three of the main lecture topics: sustainability, project management, and research. In section 4, the structure of the two main components of the course, i.e. group projects and individual presentations, are explained. In section 5, learning outcomes are evaluated using an anonymous student survey. This paper is ended with the conclusion and acknowledgement.

2 Course outline

2.1 Course components

Like most engineering programs across North America, Langara College's Applied Science diploma program offers an introduction-to-engineering course in the first year of the program. The course introduces them to the different disciplines of engineering and the teamwork design process. This course is taught by a Professional Engineer (P. Eng.) and the author assessed students based on the tasks and weightings shown here:

- Final Exam: 20%
- Midterm: 10%
- 2 quizzes: 10%
- Individual Presentation: 5%
- Final Project (50%)
  - Proposal Presentation: 5%
  - Proposal Report: 5%
  - Progress Reports: 5%
  - Poster: 5%
  - Presentation: 10%
  - Peer Evaluation: 5%
  - Final Report: 15%
- Participation: 5%

As seen in the marking scheme, the course is comprised of several sections including the following:

Instructor-led lectures. In this component, the main instructor, with the support of guest lecturers, speaks on topics related to the different disciplines of engineering. This allows students to have a better insight into engineering and the knowledge to pick a suitable major. Also, topics such as project management, sustainable development, ethics, law, and engineering research and modeling are briefly touched [8] and [9]. Table 1 outlines the main topics discussed in the lectures. Students are expected to participate through active learning strategies including brainstorming, case studies, debate, demonstration, games, surveys, jigsaw puzzles, probing questions, open-ended questions, think-pair-share, and quizzes [10].

Table 1. APSC 1010 lecture topics

Main Topics	Subtopics
History of engineering	• Ancient engineering • Industrial revolution • Second industrial revolution • Information age
Project management	• Project-management life-cycle ○ Initiation ○ Planning ○ Execution ○ Closure • Project-management tools ○ Spreadsheets ○ Work-Breakdown Structure (WBS) ○ Gantt chart • Risk management
Research	• Elements of an academic research • Data analysis • Literature review • Peer review
Sustainability	• Definition of sustainability • Sustainability and population ○ Carrying capacity ○ Malthusian catastrophe ○ Tragedy of the commons • Ecosystems and extinctions (Climate Change) • Energy ○ Fossil fuels ○ Nuclear energy ○ Hydro ○ Wind ○ Solar
Engineering ethics and law	• Framework for ethical decision making • APEGBC code of ethics • Case studies • Copyright ○ Intellectual Property (IP) ○ Trademarks ○ Patents ○ Industrial designs
Nanotechnology	• Definition, history, and applications
Artificial Intelligence (AI)	• Algorithm and flowchart • Introduction to probability-based decision making • Boolean logic • Interpolation and extrapolation • Turing test • Introduction to computer vision and pattern recognition
Information and Communication Theory (ICT)	• History of ICT • Introduction to electromagnetism and its applications
Thermodynamics	• Laws of thermodynamic and applications

Individual student presentation. Each student is required to choose a topic of interest related to engineering and technology for individual presentations. Students perform comprehensive research on their chosen topics and present their findings to the class using a PowerPoint presentation. Each student had a 10-minute presentation period followed by a 5-minute question period. The main objective of this assignment is to expose students to different topics in the world of engineering and technology by providing a research opportunity. Students also improve their public-speaking, presentation, and peer-evaluation skills. Section 4.2 of this paper elaborates on the instructional strategies implemented for this assignment.

Group project. The most important assignment of this course is the team-based group project which students work on throughout the semester. Students form their teams within the first three weeks of the course and spend the rest of the semester on a project which has research and hands-on elements. The main deliverables of this section are the initial project proposal presentation and report, biweekly progress reports, and the final presentation, poster, and report. In the last four weeks of the course, students had access to Langara College's Makerspace to finish the hands-on component of their project. Section 4.1 of this paper elaborates on the instructional strategies implemented for this assignment.

2.2 Learning objectives

This course aims to provide technical information on different disciplines of technology and sustainability while enhancing students' soft skills. The following learning objectives are incorporated into this course:

- to enhance students' understanding of engineering history, engineering disciplines, and engineering ethics;
- to enhance students' project-management, problem-solving, leadership, time-management, and critical-thinking skills;
- to enhance students' ability to do scientific research, gathering and analyzing information, public speaking, and presentation skills;
- to develop oral, written and graphical communication skills to effectively document and communicate engineering concepts;
- to raise awareness of sustainability issues in the 21st century.

3 Project management, sustainability, and research

Project management, sustainability, and research are the three main foundations of APSC 1010. In this section, the main subtopics addressed during the lecture sessions for these three topics are briefly discussed.

3.1 Project management

Project management is one of the main core competencies in all disciplines of engineering. Therefore, project management education must be integrated into the engineering curriculum to complement the students' technical training. In this course, we touch on the basics of project management principles, consider the challenges involved, and introduce the tools that can be used to facilitate the different objectives of the project. Sub-topics discussed in this section are outlined here:

- Project life-cycle
  - Initiation
  - Planning
  - Execution
  - Closure
- Leadership and communication skills
- Risk management
- Managing cost, scope, quality, and time
- Basic project-management tools
  - Work breakdown structure (WBS)
  - Gantt chart
  - Project initiation sheet
  - Risk-assessment matrix

Case studies and activities done during class are designed to encourage students to manage the different phases of the project life-cycle and use basic project-management tools. Students are encouraged to apply these techniques to their group projects. Some of the tools introduced in the course are shown in Figure 1.

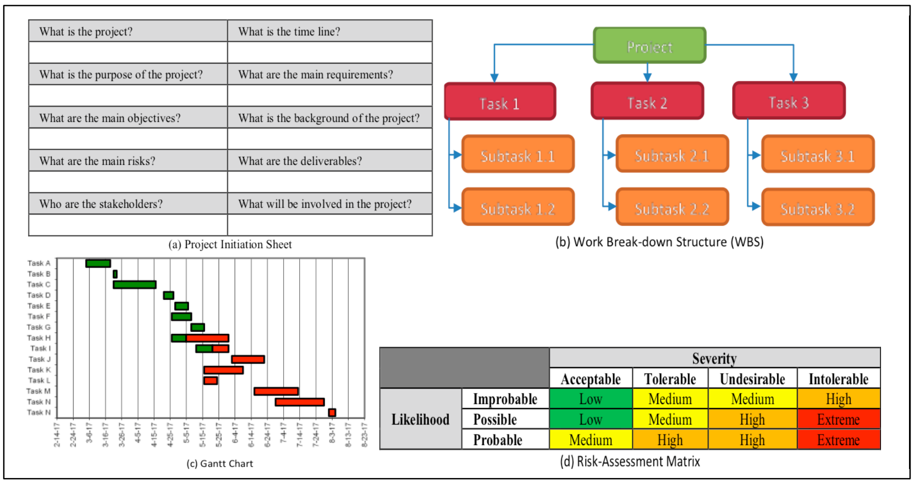


Fig. 1. Project management tools introduced in the course [11]

3.2 Sustainability

Incorporating sustainability into engineering education is a vital necessity. To raise awareness of undergraduate engineering students about sustainability concepts, we have incorporated this topic into our lecture syllabus. In this course, some of the issues the planet is facing are introduced using evidence- and fact-based data. Students are encouraged to think about and research solutions for these problems in their individual research and group project. The main topics discussed in lecture include:

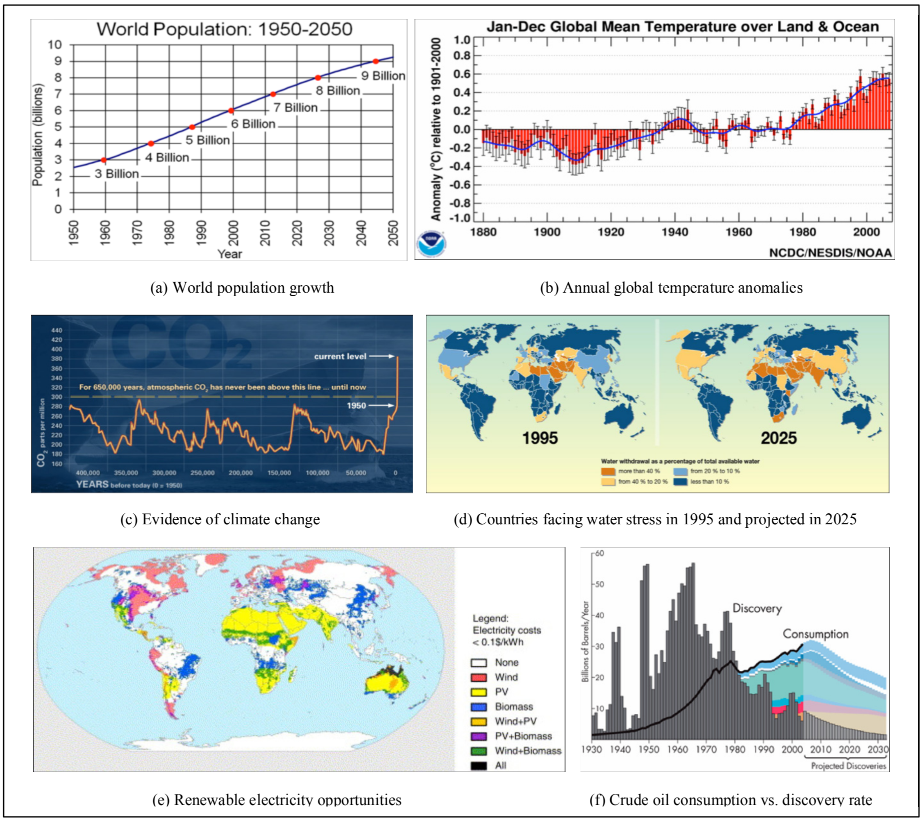
- Definition of sustainability
- Sustainability and population
  - Carrying capacity
  - Malthusian catastrophe
  - Tragedy of the commons
- Ecosystems and extinctions
  - Global warming and climate change
  - Mass extinction
- Energy
  - Fossil fuels
  - Nuclear energy
  - Hydro
  - Wind
  - Solar
- Water crisis
  - Virtual water

Figure 2 shows some of the factual statistics used in course content related to sustainability issues such as population, climate change, energy, and water crises.

3.3 Research

Hands-on research used as an essential element of project-based learning can increase students' retention and motivate them to pursue a career in engineering [13]. To increase students' understanding and awareness of the subject matter, a research component has been added to the course. However, since most undergraduate students have no prior training on how to do research and how to find resources, a lecture component has been devoted to this topic. In this section, students are introduced to basic principles of research through examples, exercises, and demonstration. Some of the subtopics discussed in this part are outlined briefly:

- Formulating the research objectives
- Quantitative vs. qualitative research
- Inductive vs. deductive reasoning
- Literature review
- Academic databases
- Peer review



(a) World population growth

(b) Annual global temperature anomalies

(c) Evidence of climate change

(d) Countries facing water stress in 1995 and projected in 2025

(e) Renewable electricity opportunities

(f) Crude oil consumption vs. discovery rate

Fig. 2. Sustainability concepts introduced in the course using statistical data [12]

- How to give feedback
- Modeling and simulation tools
- Independent vs. dependent variables
- Accuracy vs. precision
- Data analysis and interpretation

4 Group project and individual presentation

In this section, the two main components of the course, the students' group projects, and individual presentations are discussed in detail.

4.1 Group project

Cooperative project-based learning (CPBL) is a very effective inductive technique to teach complicated open-ended engineering problems [14]. CPBL not only improves students' technical and design knowledge, but also enhances many soft skills, including independence, accountability, interpersonal and teamwork skills, project management, problem-solving, and self-assessment. However, the effectiveness of this method relies heavily on several factors such as course structure, effective team forming, and team performance evaluation [6].

Figure 3 is a flowchart for the group project phases in APSC 1010 which will be clarified in the following subsections.

Fig. 3. APSC 1010 project phases

Team forming and topic selection. There are several methods for team formation including random assignment, self-selection, personality-test selection, experience-based selection, performance-based selection, and interview-based selection [15].

In APSC 1010, team formation is done through self-selection, based on the students' knowledge of each other's educational background, specialized knowledge, and skills. Based on previous studies, students prefer to form their own teams rather than forced grouping by the instructor [16]. Therefore, in the first three weeks of the course, many group activities, discussions, and games are integrated into the lecture to enhance students' social interactions. Two informal questionnaires are also given out in which students specify their technical interests and specialized skills as well as their project-management capabilities (leadership, communication, problem-solving, risk management, and planning). By the end of the third week, teams are formed based on self-selection with the instructor's guidance and support.

Project teams then meet regularly to select an open-ended topic of their own interest, with achievable goals for the theoretical and hands-on components, which can be done within a certain budget. The instructor provides the necessary research resources and guides the groups in tailoring their topics so that the work is authentic, based on real-life problems, low-budget, and challenging. These meetings also force students to repeatedly modify the scope of their project as a part of the experiential learning process [3], [6], and [17].

By the end of Week 4, teams propose their topic in a presentation to receive feedback from their peers and the instructor. A formal proposal report, on which students receive extensive feedback, accompanies the presentation. This course is supported by a technical communication course which further enhances the students' writing and presentation skills.

Progress reports and Makerspace meetings. The teams are expected to meet on a weekly basis to discuss problem-solving methodologies. Instructor input is given when necessary to provide research literature and differing points of view. To avoid poor performance due to dysfunctional teams, progress reports and peer evaluation techniques are among the project deliverables. Each group submits biweekly progress reports which identify: project information, project status, summary, list of deliverables, list of accomplishments, and plans for the next two weeks [18].

In the last four weeks of the course, students have access to Langara College's Makerspace which expands experiential learning opportunities and allows students to gain a skillset outside the traditional classroom. The Makerspace is equipped with 3D printers, a CNC router, a laser cutter, scanners, a sewing machine, microcontrollers, and a selection of hand tools. This time is devoted to guided work on design projects, with close interaction between the instructor and students.

Budget management is an important criterion for evaluation and provides students with a better understanding of the processes and roles of business and government within society. Rapid-prototyping available through 3D printing and electronic component integration are two strategies that can mitigate project costs in addition to increasing the usability and complexity of the project.

A brief introduction to 3D printing is done by a guest lecturer. Students are then self-taught to use CAD software packages such AutoCAD or Sketch to model a 3D concept. They then create a solid model using a variety of printers available at the Makerspace. Basic circuitry and working with open-source microcontrollers are also briefly discussed. These strategies simplify the process of design and offer numerous experiential learning advantages for students. The student-centered learning approach and constructivist learning activities were promoted and implemented in this phase [19]. Figure 4 shows pictures of Arduino and RaspberryPi microcontrollers and MakerBot 3D printers available at Makerspace.

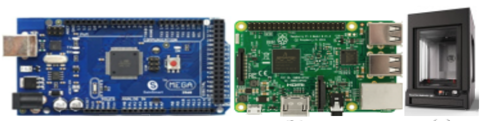
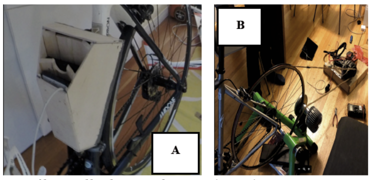


Fig. 4. Available equipment at Makerspace used for prototyping (a) Arduino Mega, (b) RaspberryPi 3, (c) MakerBot Z18

Final presentation and evaluation. At the end of the term, groups deliver a 15-minute PowerPoint presentation in front of the class followed by 5 minutes of questions. In this presentation, students explain the design process and challenges to defend their design choices. Work division, time-management, and budget are also discussed in detail. Finally, a demo of their final prototype is shown to the class. A final 3000-word report as well as a poster, which outline the motives, history, methodology, results, and references, accompany this presentation. Each team member completes a scoring matrix, rating every team member's total contributions to the project. These scoring matrices are averaged amongst all team members and used to weight the project mark according to individual contributions to the success of the project [20]. The criteria for peer evaluation are:

- Listening skills
- Openness to Others' Ideas
- Preparation
- Punctuality
- Contribution
- Leadership

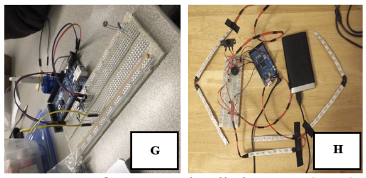
Figure 5 shows some of the project results delivered in 2016-2017.



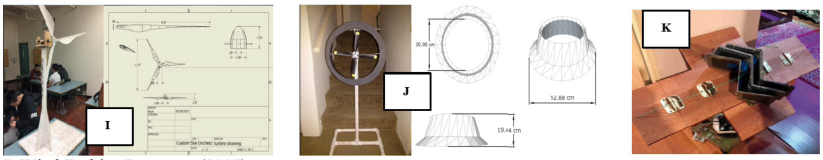
A. Bike Cell-Phone Charger (2016)
G. W., K. R., and J. C.
B. Pedal Powered Electric Generator (2017)
A. S., T. K., and Z. Y.

C. Vertical Solar Wind Turbine Prototype (2016)
A. H., B. O., D. A., D. S., and J. R.
D. Solar Tree Prototype (2017)
F. S., A. M., G. S., S. K., and S. K.

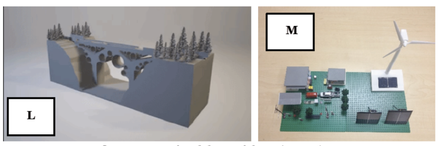
E. Electricity Generation Using Peltier Tile (2017)
Z. A., A. D., D. P., and Y. R.
F. Fuel-Cell Toy Car (2016)
N. B., N. S., E. S., and N. Y.



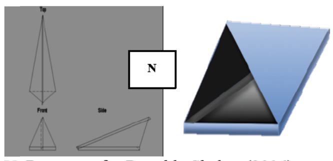
G. Prototype for Automatic Blind Opener (2017)
A. N., K. M., D. S., and S. S.
H. Turn-Signal Bike Jacket Prototype (2017)
B. W., I. Y., J. R., and K. S.



I. Wind Turbine Prototype (2017)
S. F., T. L., C. R., A. S., and R. T.
J. Lens Wind Turbine (2016)
A. C., R. C., and U. A.
K. Origami-Inspired Portable Solar Panel (2017)
B. J., A. K., J. M., and L. Y.



L. Prototype for a Sustainable Bridge (2017)
O. B.-R., C. H., T. S., and B. T.
M. Prototype for Self-Sufficient Auto Service Station (2017)
A. R. R. and Y. R.



N. Prototype for Portable Shelter (2016)
M. C., C. G., S. H., S. T., and M. W.

Fig. 5. APSC 1010 sample projects delivered in 2016-2017

4.2 Individual presentation

Instilling enthusiasm via providing real-life research opportunities has shown to encourage undergraduate students to pursue a degree in engineering and solidify their understanding of theoretical concepts.

In addition to the presentation required for the group project, each student of APSC 1010 must give an individual presentation on a technical topic of interest. To prepare students for this assignment, one lecture topic is devoted to the process of doing academic research which was briefly discussed in section 3.3. Students are introduced to the literature-review process, technical research procedures, and scientific reasoning.

Students are required to deliver a 10-to-15-minute presentation in front of the class on a topic of interest related to any field of technology and engineering. In this PowerPoint presentation, students introduce the topic, provide a brief history, present the facts, and their unique evaluation based on a cost-benefit analysis. At the end of the presentation, the presenter must answer questions from the audience. Classmates are encouraged to provide a peer evaluation on the quality of the presentation. The scoring criteria shown in Table 2 was used to evaluate the quality of presentations.
A list of presentation and project topics is presented in Table 3.

Table 2. Marking criteria for oral presentations [21]

Category	Scoring Criteria	Total Points
Organization (15 points)	The type of presentation is appropriate for the topic and audience.	5
	Information is presented in a logical sequence.	10
Content (45 points)	Introduction is attention-getting, lays out the problem well, and establishes a framework for the rest of the presentation.	5
	Technical terms are well-defined in language appropriate for the target audience.	5
	Presentation contains accurate information.	10
	Material included is relevant to the overall message/purpose.	10
	Appropriate amount of material is prepared, and points made reflect well their relative importance.	10
	There is an obvious conclusion summarizing the presentation.	5
Presentation (40 points)	Speaker maintains good eye contact with the audience and is appropriately animated (e.g., gestures, moving around, etc.).	5
	Speaker uses a clear, audible voice.	5
	Delivery is poised, controlled, and smooth.	5
	Professional language and pronunciation are used.	5
	Visual aids are well prepared, informative, effective, and not distracting.	5
	Length of presentation is within the assigned time limits.	5
	Information was well communicated.	10

Table 3. List of group project and presentation topics (2016-2017)

List of Group Project Topics	List of Individual Presentation Topics	
• H_2 fuel-cell powered toy-car	• Robotic surgery	• Carbon fiber
• Wind-powered buildings	• Hydro power	• GMO
• Peltier effect	• Stretch ceiling	• Smart pipe
• Automated blind system	• 3D printing	• Carbon nanotubes
• Pedal-powered generator	• Lens wind turbine	• Turbo chargers
• Solar tree	• Jet engines	• Nano-drugs
• Portable solar panel systems	• Rotary engines	• Maglev trains
• Self-sufficient service station	• Self-driving cars	• Cyclotron
• Turn-signal jacket	• Hydrofoil	• Green roof
• Algae-based air filter	• Bitcoin	• Hybrid supercars
• Dual-purpose solar panel	• Solar roads	• Quantum calculus
• Emergency power charger	• AutoCAD	• Cybersecurity
• Solar-powered farm	• Virtual reality	• Biomimicry
• Sustainable bridge	• Human augmentation	• AI
• Piezoelectric effect	• Moore's law	• Supercomputers
• Automatic irrigation system	• Patents	• Video games
• Greywater turbine	• Dutch agriculture system	• Geothermal energy
• Bike charging unit	• GPS	• Bioinformatics
• Rainwater power generator	• Fuel cells	• Artificial photosynthesis
• Vertical solar wind turbines	• Skin-touch technology	• Janicki omni-processor
• Railgun	• Bionic	• Prosthetics
• Toddler's signaling shoes	• Drone	• Drones
• Portable homeless shelters	• Night-vision technology	• Pascal law
• Wind lens turbine technology	• Gravitational waves	• Algae fuel
• Water clock model	• Quantum mechanics	• Thermodynamics
• Hydro-energy model	• Near-field comm. (NFC)	• Big data
	• Ecological products	• Flywheels
	• Ocean clean	• Dust explosion
	• Solar panels	• Nuclear energy
	• Hubble telescope	• Hyperloop
	• 5G system	• Indonesian pyramids
	• Twin towers failures	

5 Student survey

To evaluate the effectiveness of this course in achieving its objectives, an anonymous voluntary survey was conducted at the end. This survey consisted of a series of close-ended questions asking the students, on a scale of 0 to 10, to what extent they agreed with a set of fixed statements. Table 4 shows the questions and the percentage of students providing a number greater than or equal to 7. More comprehensive results are provided in **Error! Reference source not found.**.

The results confirm the effectiveness of this course in achieving its goals. Based on student feedback, diversifying the lecture topics to cover more disciplines of engineering would be an area to invest on for future terms.

The impact of the active learning strategies is not identical on all students because of differences in motivation and commitment [22]. Therefore, as this survey demonstrates, the combination of lecture, group project, research, and presentation can improve both technical and non-technical skills such as soldering, microcontroller programming, 3D printing, working with hand tools, communication, time management, public speaking, teamwork, project management, and problem-solving.

Table 4. Survey questions and percentage of responses with answers ≥ 7/10

	Evaluation Question	Percentage of Responses ≥ 7/10
Q1	Did the individual presentations help you learn about different engineering/technical concepts?	84.3%
Q2	Was your knowledge of how-to-do research and literature review expanded because of this course?	68.6%
Q3	Did the presentations scheduled for the course improve your presentation skills?	88.5%
Q4	Did the group project improve your project-management skills?	84.6%
Q5	Did the group project improve your communication/interpersonal skills?	84.6%
Q6	Did the group project help you improve your time-management skills?	73.1%
Q7	Was this course successful in increasing awareness about the sustainability issues?	75%
Q8	Did you enjoy the guest lectures organized for the course?	69.4%
Q9	How satisfied were you with accommodations provided for the group project?	78.4%
Q10	Were the scheduled progress reports helpful in making sure you are on track?	73.1%
Q11	Did this course help you realize which engineering discipline you might be more interested in?	69.2%

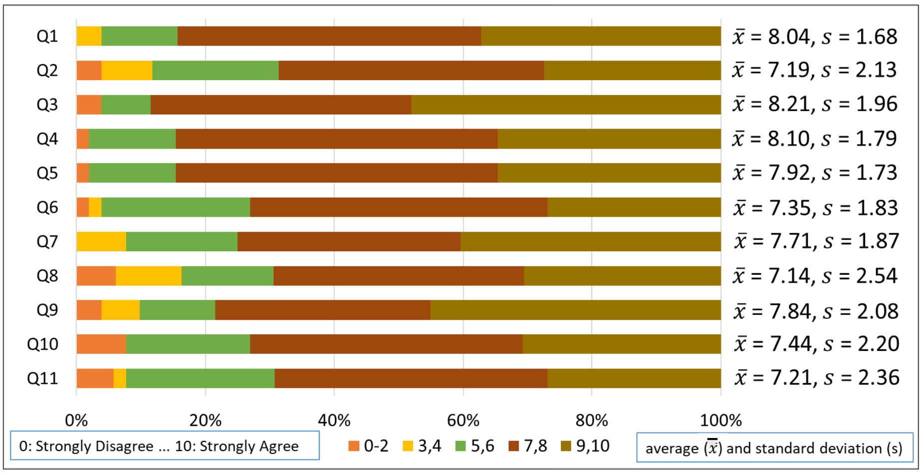


Fig. 6. Detailed survey results

6 Conclusion

This paper demonstrates how a first-year engineering-design course is optimized to raise awareness of sustainability issues through project-based learning and research components. Learning outcomes are evaluated using an anonymous student survey. Different components of the course including lecture, group project, and individual presentation were discussed. The process of group-project supervision, marking criteria, and survey results were presented in detail.

Based on the results of group projects, individual presentations, and a student survey, the following course objectives have been achieved:

- Improving students' project management skills and teamwork;
- Improving students' communication and public-presentation skills;
- Raising awareness of sustainability issues;
- Introducing different fields of engineering.

7 Acknowledgement

The author would like to thank Ms. Amy Yeung for proofreading this paper. Special thanks go to the following colleagues at Langara College for their valuable support: Dr. Csilla Tamás, Dr. Jacqueline Nelsen, Dr. Todd Stuckless, Mr. Philip Robbins, Mr. Henri Lei, Dr. Sirine Maalej, and Mr. Kelly Sveinson.

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This article is the extended version of the poster presented at the CEEA 2018 conference held in Vancouver, BC, Canada, 3-6 June 2018. Article submitted 14 March 2018. Resubmitted 02 April and 15 April 2018 Final acceptance 07 May 2018. Final version published as submitted by the author.