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Implementation of a Case Study in an Engineering Science Course: A Pilot Project for Increasing Experiential Learning

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Abstract

It is valuable for instructors to provide real-world connections in their curricula so that engineering students can appreciate and practice integration and application of knowledge. This is essential in both engineering science and design. A variety of mechanisms have been used to accomplish this, including guest speakers, field trips and company-sourced design projects. Another useful mechanism to achieve this objective is the case study.

For this reason, a case study was developed for a second year mechanical engineering solid mechanics course which involved the redesign of a chassis for model fuel cell cars. Five hands-on activities were developed around this case study to give students an opportunity for practical problem solving and to integrate concepts learned throughout the course. The goal for using the open-ended case study was to connect engineering science analysis to a realistic engineering design, as well as foster experiential learning. This implementation acted as a pilot project as part of the university's long term goals to shift the mechanical engineering program towards this type of learning.

The selection process for the fuel cell car case study is discussed with a focus on using design to improve engineering science courses. The course instructor provided their comments and observations, teaching strategy and learning outcomes. There were difficulties associated with setting up and coordinating all activities since this was a first-time implementation of the case study and the first use of any case study in this course. From this experience, recommendations for improvements are discussed, specifically regarding the hands-on activities, the enhancement of student experience, and creating cross-course connections in future implementations.

Introduction

The mechanical engineering department at the University of Waterloo is pushing to have experiential learning brought more often and earlier on into the program. There is a demand for more curriculum components that increase students' problem solving and design skills as well as the ability to handle open-ended problems. This is especially desired right away in first year courses so that students know to expect this type of learning for their entire undergraduate careers. This would also help them successfully complete their fourth year design course since this would no longer be their first exposure to open-ended design. The pilot project course is part of a wider initiative at University of Waterloo and its outcome is meant to address learning objectives for the university's long term goals. The use of a case study and its authentic engineering problem was decided as an appropriate method to work towards this wider initiative.

Engineering science is the discipline dealing with the art and science of applying scientific knowledge to practical problems. There is a need for pedagogical methods that push for this experience, including the case study. A case study is a real-life problem that provides context and complexity, requiring the case-reader to apply knowledge and skills in order to properly develop a solution[1, 2]. The open-ended nature of cases reinforces problem-based learning and encourages active participation[3]. They can also appreciate that there are multiple solutions[5] which promotes creativity and innovation[4], as well as encourages tolerance for ambiguity[1, 6, 7].

With case studies, students practice skills in a way that increases knowledge retention[8, 3]. Case studies are also different than typical textbook problems which are usually oversimplified theoretical representations focused on core principles[9]. It is clear that students have to practice basic principles and that lecturing is a valuable pedagogical method; however, there is also a need to reverse the trend of engineering students who graduate without the full skill-sets that are fundamental to their professional practice[10]. Our increasingly fast-paced society requires a change in the way engineering is taught. Many companies now rely on skills gained during post-secondary education instead of mentorship during the first years of work. Therefore graduates need more than technical skills, but also non-technical skills such as teamwork, communication, problem-solving and accountability[8]. A case study is an effective tool[1] that has shown to improve higher-order cognitive skills[11] and critical thinking[4]. Evidence suggests that cases create a positive attitude towards learning, and any skills obtained can carry into future endeavours[9, 7]. Students are known to learn more effectively when they are actively involved with their learning, and it challenges them to accept responsibility for their own education[5].

Traditional uses for case studies in engineering

Although the case method has been proven to be an effective method and is common practice in other programs such as business, it is less prevalent in engineering education[4]. Engineering courses are still developed to cover theory and concepts through a traditional lecture method. Typically, engineering programs use failure case studies to teach design[3]. Failure cases allow for storytelling with drama which causes an emotional attachment[8]. This is usually due to the fatalities in the story and it is effective in increasing engagement[12]. This type of case study is a valuable resource for instructors since they highlight safety[9] and the subsequent changes to standards and procedures[13]. There have been studies on the effectiveness of these cases which show learning enhancement of graduate attributes[12, 14]. Therefore, there has been considerable work in putting more failure cases into engineering programs[13].

Other case studies are implemented to a certain extent; however, they are less common and traditionally used in engineering design or ethics courses[6, 7, 15]. The main reason for this is that ethics and design require context and complexity in order to properly demonstrate the disorder and unrestrained environment of real-world problems. With specific regards to ethics, case studies can show a student that being a good person does not necessarily mean analyzing an ethical issue will be easy for them[9]. With respect to engineering design, case studies provide a more realistic problem: students may have missing information, a broader scope to consider, or potential issues arising from a certain situation.

Engineering science courses

There is equal value in incorporating case studies into engineering science courses, beyond their typical placement in design and ethics courses. A student's education should be balanced, especially between engineering science and design[7]. Engineering curricula can often separate these two streams[16]. The principles taught in these engineering science courses are directly related to design problems. The case study can illustrate the application of engineering science, and show students that engineering science principles are essential for design.

Engineering cases are still mainly used in design courses and this is potentially because they fall more easily within the scope of a case study. Cases and design courses are both open-ended, complex and any potential solutions tend to diverge. There are also more available case studies on design, especially with an interest in failure cases. Engineering science courses usually focus on problems with single correct answers, are non-evolving, and an easily converging solution. They are important for providing strategies on problem-solving and developing analytical skills. It is important for students to take a real-world problem, determine its essence, apply an analysis, and then make design decisions based on this analysis[17]. In order to accomplish this, a case study needs to be well selected.

Case selection criteria

Case selection is vital to the level of engagement and depth of learning. It is important to select an appropriate case study that:

1. Directly applies to the content of the course,
2. Is clear as to what the students will be doing (what are the case activities?),
3. Provides a sufficient challenge at an appropriate skill-level for the students, and
4. Instills interest and engagement.

One method of increasing interest in the case itself is to select one that is related to the career interests of the students[1, 4, 13]. Choosing a case study in their field can highlight the type of experience they hope to gain after graduation, which is appealing to students[4]. These cases are a simulation of "on-the-job" learning[2].

A large group of students can make this selection difficult because their areas of interest will be more diverse, but a single case can still meet many students' interests or the instructor can select multiple cases to better match the range of interests. Another criterion for increasing engagement is verifying that the case study's applications relate to the current world. This will show students that what they are learning is relevant[18], and that the problems faced in the case could be similar to an issue they will deal with in the future.

Although it is beneficial for engineering students to analyze high-profile events, they also need to be exposed to issues in a more typical context[2]. In other words, cases should involve "everyday" people. Case studies drawn upon personal experiences are no less important for their education[7]. Cases that use multi-media are usually better[3] since they are a more exciting format and provide a better connection to the real world[5].

Besides an exciting format, students are more attracted to a case study with an appropriate challenge. This means the complexity of the case study must be well selected. It is difficult to balance between case studies that require too high-level of critical thinking and cognitive skills, and case studies that are too simplistic. Both of these scenarios can create a negative learning environment. If the case relies heavily on a detailed and specific engineering tool, this will weaken the impact of the case because of the focus on technique, which detracts from the application. If the case study is too simplistic, the students will be less engaged and the lack of challenge will foster a belief that only low-level concepts will be needed when they enter the workplace[18].

All four case selection criteria were considered for the second year mechanical engineering course. After analyzing desired complexity, applications, activities and student interests, a case study was selected that focused on the chassis of model fuel cell cars.

Background

A model fuel cell car project was introduced in the Mechatronics Engineering program at the University of Waterloo in 2012 to increase students' hands-on experience in first year courses. The students were asked to assemble the model car from a commercial kit and then complete labs on hydrogen fuel cells, electrical circuits, and programming, with the ultimate goal of having the vehicle autonomously follow a test track. Although the project was generally successful in integrating multiple concepts[19], there was a desire to improve these model cars. They had limited maneuverability, were not easily controllable by the students, and did not run for sufficient periods of time using the hydrogen fuel cells. Many of these limitations required a detailed look at the mechanical design of the vehicles. Therefore, an opportunity to redesign the chassis (see Figure 1) emerged as the source for a case study in the second year mechanical engineering course. Its problem statement asked students to analyze the chassis for further improvements that would increase reliability and performance. A series of case activities guided the students through the analysis of the chassis. To reiterate, the mechanical engineering pilot project course was the first exposure the students had to the fuel cell cars. They were aware of the project in the mechatronics program and had also heard complaints from the mechatronics students regarding the functionality of the cars. The case study formalized this issue and asked the mechanical engineering students to analyze and redesign the chassis to support another program on campus.

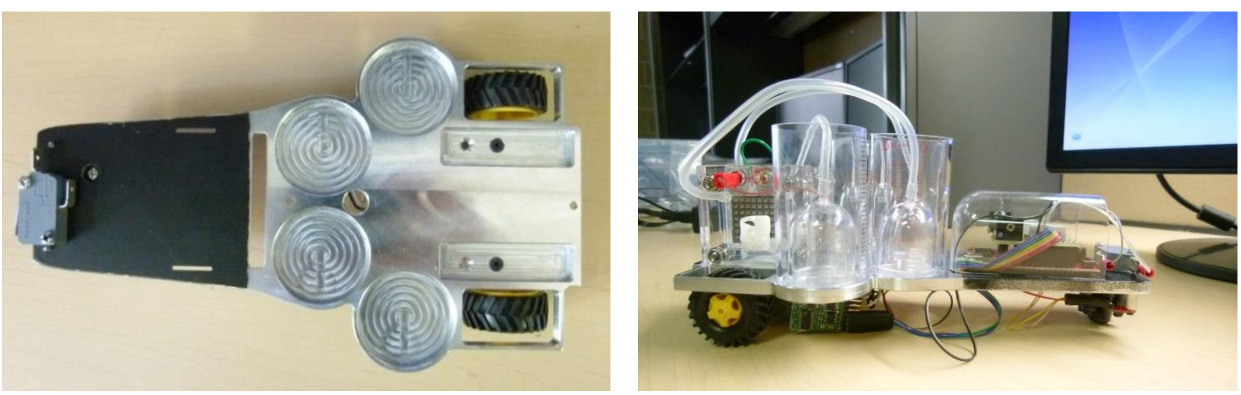

Figure 1: Top view of aluminum chassis for the model fuel cell car (left) and side view of chassis with all its components (right)

A group on University of Waterloo's campus, Waterloo Cases in Design Engineering (WCDE), develops case studies to support engineering faculty and enhance the curriculum. This case study was selected from their database for its locality and its ability to connect to multiple concepts. First, the students were familiar with the model fuel cell cars since they were already being used on campus for another activity. This made the case relevant, current and interesting to the students because it related to their own university. Second, the open-endedness of the case study allowed for multiple aspects of the chassis to be analyzed and linked to various course concepts. The students would be challenged to re-design the chassis by applying many principles that they had been taught throughout the term. This would also be a hands-on case study since the students were given the opportunity to work with the model fuel cell cars throughout the entire term. This not only increased the value of the case study, it created an experiential learning environment.

Implementation strategy

There are many implementation strategies when using case studies and there is no single correct approach[9]. The following example of a specific implementation is meant only to act as a resource and point of discussion.

The goal of the case study was to motivate an analysis based on relevant engineering principles, which was key in the way it was implemented. As students were taught theory in the classroom, they were given a series of activities that demonstrated applications of these principles. The case study outlined design goals based on feedback from previous use of the cars in another program. The high priority design goals are shown in Table 1. The high priorities were not fabricated by the instructor; instead, these were taken directly from a report done by a co-op student whose job was to analyze the fuel cell cars for areas of improvement. This was explained to the students so that they understood the priorities were based on real world feedback.

Table 1: High priority design improvements for model fuel cell cars

a)	The weight of the new chassis is still heavier than the original fuel cell car, which reduces run time.
b)	The fuel cell car`s maneuverability is limited by the size of the chassis and the type and number of sensors.
c)	Running time is still short (2 minute approximately) so it would be beneficial to increase this.
d)	New fuel cell car requires twice as much fuel in order to maintain original run times.

The case activities, course concepts and report due dates were planned for five stages, summarized in Table 2. Ultimately, the students recommended design improvements for the next version of the chassis based on the case activity results. Students worked in teams of five and completed five activities. Although every student attended all case activities and provided documentary evidence of any testing, each student was only responsible for a comprehensive analysis report on a single activity. Therefore, between the five group members, there was only one report for each activity. Students referenced previous reports from their group members as a means to further their analysis and to eventually develop a final design.

Table 2[1]: Overview of dates connecting course concepts with case activities

Semester Week	*Course Concepts Being Taught in the Classroom*[20]	*Case Activity Number*	*Case Activity Description*
2 & 3	• Equilibrium • Free body analysis • Center of mass • Forces	1	Loading and Free Body Analysis of the existing model FC cars
4 & 5		2	Analysis of the existing Traxxas Telluride cars (a commercial car)
6 & 7	• Torsion	3	Measurement of the shaft, torque and load
8 & 9	• Bending	4	Chassis bending for the FC car
10	• Cumulative for weeks 2 – 9	5	Development of an alternative chassis

Since the case study was planned as a term-long project, the goal was to connect various course concepts to the case activities. Students could see that the course concepts taught in class built on each other and the engineering science principles were all necessary to properly analyze and redesign the fuel cell cars. The case would also act as a discussion point during lecture to demonstrate an application of core concepts. Since the case activities were an integral part of the course, a heavier weight was assigned to the case study overall. As seen by Table 3, the case study and its activities comprised 30% of the students' final grade.

Table 3: Course syllabus outline for the case study and its activities

Course Component	% of Course Evaluation	Description
Case Activity Attendance	10 %	Students were given 2% of their grade for every activity they attended (no partial grades). This included a photo of themselves conducting each activity and a paragraph explaining the results
1 analysis report	20 %	Each student wrote one comprehensive analysis report for a selected activity.
Total weight	*30 %*	

Groups of five were selected for scalability and for logistical purposes. There were 116 students in the course and this group size was deemed manageable based on resources such as Teaching Assistants, space, time available for marking, case activity space, number of fuel cell cars, etc. The room in which case activities were conducted was relatively small, with only 2 to 3 groups present at one time and with at least two instructors. This made the instructor to student ratio very high. The group sizes were made scalable so that this "small room feel" could be accomplished and so students could be more engaged by increasing contact with their instructors. This group size also made it possible for each group to take a car home for the semester. The instructors provided activity objectives to the students (Table 4) along with open-ended guidance on how to complete each activity. Each round of students (2 to 3 groups) took an hour per activity with a full-time staff member also putting time towards preparation and team management on a weekly basis.

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[1] Although the dates listed in Table 2 were given to the students at the beginning of the term, they were not possible because space for these activities was not procured until later in the semester. The delay was not desired and original dates are provided since they represent an ideal timeline.

Table 4: Case activity objectives

Case Activity	Objectives
1	• Document the current vehicle, its loading and its mechanical details before teams began to consider any new designs • Students were asked to create an accurate loading diagram showing the location and mass of every part, including center of mass • Students were required to generate a free-body diagram of components and assemblies
2	• Document the details of a similar vehicle for comparison with the in-house designed FC car • Students conducted the same activity on a commercial Traxxas car and were required to generate the same results as activity one
3	• Document the details of the existing drive system and determine the source and magnitude of its losses • Students were then asked to analyze ways to reduce energy loss • Based upon these observations, students also considered the motor efficiency and ways of improving its use of energy for the fuel cells
4	• Document the details of the existing chassis and measure the resistance to bending of the FC car chassis • Based upon these observations, they were asked to consider the impact of the chassis flexibility in the vehicle performance
5	• Propose and fabricate an alternative to the existing chassis that would potentially improve the handling of the FC car based on test results and analyses • All required loads and components had to be considered as well as the relative improvement in energy consumption and duration of use.

After implementing the case activities, the recommendations and design decisions from seven groups of students (comprising 35 students in total) were collected and analyzed. As part of a work term report requirement, one of the Teaching Assistants of the course sought to analyze the student design process based on the five case activity reports. To do this, it had to be known which individuals comprised a group. This was not necessary to track while the course was being conducted and so there was limited data on group numbers throughout all case activities; only seven groups were found as a complete data set. This data is summarized below in Table 5.

The frequency of recommendations for Case Activities 1 to 4 was recorded and then refined to remove any redundant improvement suggestions. Afterwards, the student reports for Case Activity 5 were reviewed and improvement trends were recorded, specifically those that were based on previous activities. The far right column of Table 5 represents the percent of groups that actually implemented the respective recommendations in their final design.

It is clear to see from Table 5 that altering the chassis material (4A) was the most frequently implemented improvement for the fuel cell car by the students. Second to that improvement was shortening the chassis (1B) to reduce the inertia, followed by placing the center of mass at the rear (1C), geometrically centering the center of mass (1D), and making the vehicle compact (2A). The design paths for each group were created and are shown in Figure 2 below.

Table 5: Compiled and refined recommendations based on case activities 1 to 4

Case Activity	Most Common Recommendations for Fuel Cell Car Improvements		Recommendation Frequency	Implemented in Final Design
1	1A	Reduce the weight of the chassis	46 %	5 %
	1B	Shorten chassis (minimize rotational inertia)	46 %	52 %
	1C	Create a rear center of mass	32 %	33 %
	1D	Center the center of mass (even wheel forces)	27 %	29 %
2	2A	Compact components	39 %	29 %
	2B	Lower center of mass	35 %	5 %
	2C	Even weight distribution	35 %	5 %
	2D	2 front ball rollers/front wheels	17 %	5 %
3	3A	Lubricate gears	50 %	0 %
	3B	Increase quality of gearbox (gears and motor)	50 %	5 %
	3C	Improve gear ratio	21 %	0 %
4	4A	Lighter and/or weaker material for chassis	64 %	86 %
	4B	Reduce material for chassis	27 %	33 %

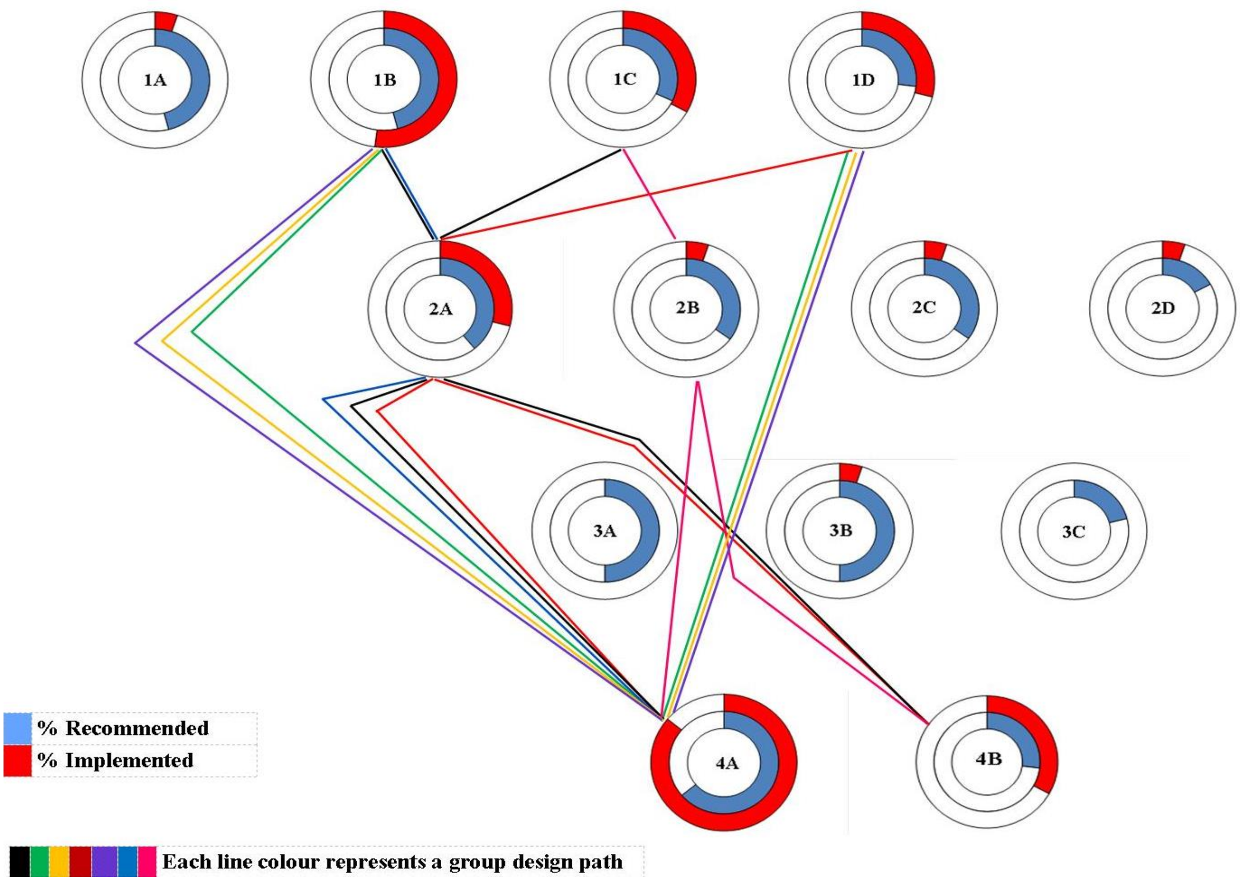

Figure 2: Design paths based on recommendations (blue) and implementation frequencies (red)

Design paths analysis

In order to analyze the design decisions made by the students, data from activity reports was investigated. As seen in Figure 2, the design paths of all seven groups do not cross any of the recommendations from Case Activity 3. This means that the groups purposefully did not wish to do anything that was related to the motor and gearbox even though improving the efficiencies even by a small amount could result in a dramatic improvement of the fuel cell car performance. Due to Case Activity 5 only requesting a change in the chassis, the groups neglected to implement any of the findings from the third activity. The purpose of improving the run time of the fuel cell car was forgotten. On the other hand, more groups implemented a change in chassis material than groups who recommended this. Many students jumped straight to switching the material of the chassis even though in the first clinical activity there were many reports suggesting modification of the original chassis. Case Activity 4 restricted lateral thinking concerning the chassis and created a pack mentality to replace the chassis with a lighter material. Many of the alternative designs were shaped differently but the general placement and structure was the same, a plate or board of material with all of the components on top.

It was a frequent observation that the students wished to reduce the length of the chassis to reduce the effect of the parallel axis theorem. The position of the center of mass was also a common recommendation (1C and 1D) but a conflict existed between reports on where it should be located. The discrepancies suggest that students needed further clarification of relevant engineering science principles and that their design decisions were influenced by varying interpretations of the main objective. Both shortening the chassis and moving the center of mass tied in well with concepts being taught in class during weeks 2 to 5. It was valuable to see that students were recommending design changes based on core course concepts and that they were also able to apply these concepts to a real-world design.

The recommendation to reduce weight from the original design (1A) was not applied as frequently as expected to the students' final designs based on how frequently this suggestion was made. Although students appreciated that the weight of the chassis was unnecessary for its application, this did not reflect in their final designs. This may stem from many students' belief that completely redesigning is a more effective method than improving a pre-existing design.

The recommendations from Case Activity 2 were barely implemented other than the concept of organizing the components in a compact fashion (2A). Due to the Traxxas car's ability to manoeuver and run easily in comparison to the fuel cell car, the students' recommendations leaned towards trying to apply the features of the Traxxas car to the fuel cell car, regardless of the application. Many groups traded off the fuel cell car's stability for a compact chassis. This decision was most likely based on the fact that the fuel cell cars run on flat courses and do not need high stability. It was good to see students make these types of trade-offs since they were considering the context and application of their design objectives.

The recommendation of applying gear ratios (3C) in order to have a higher speed output for the gearbox would have the disadvantage of losing torque. Using gear ratios to increase the output angular velocity at the same input power would result in the output torque decreasing. Therefore this recommendation highlighted the need to increase class discussions on gear ratios, torque and power which are related to the topics taught during weeks 6 and 7. It was ideal to see this response from the students' design applications so that improvements can be made for the next cohort in to order to ensure these concepts are better explained in the classroom.

Many students sought out a new material for a chassis after learning the deflection of the chassis to be in the magnitude of tenths of millimeters. The majority of the reports (64%) suggested altering the chassis' material. This is likely due to Case Activity 4 demonstrating to students that the chassis is unnecessarily rigid and dense. This directly connected with the theory being taught during weeks 8 and 9. Based on the reports from Case Activity 4, it was clear that students were able to understand the impact of bending on the fuel cell car chassis and were also able to analyze whether the bending property of the chassis was appropriate for its application.

Discussion

There was general positive feedback from the students and the instructor based on this case implementation. A survey was conducted to gather more definite results on student feedback; however, these results do not have ethics approval at this time. Data will continue to be collected regarding this pilot project in subsequent course offerings in order to evaluate its ongoing contribution to University of Waterloo's long term goals.

The hands-on experience from the case study was well received since the students could better analyze the model FC cars because they had the opportunity to take an FC kit home for the semester. The students appreciated having a visual and tangible connection to concepts being taught in the lectures. The positive impact of the case study was also reflected in the quality of the student reports. Based on analyzing student recommendations and design decisions, the students were able to apply concepts taught in class to the case activities. Students provided feedback that they enjoyed applying theory to a real design challenge so that they could have a better appreciation for the course. The instructor was able to take case activity reports as feedback on whether the students had a deeper understanding of relevant lecture topics based on whether they applied these concepts to the fuel cell car correctly. This implementation design was effective since the instructor was able to understand which concepts needed more of a focus by relying on the hands-on, engineering design to highlight students' disconnection of theory to a real world problem. These types of experiences are vital since fewer students entering engineering have pre-existing hands-on technical knowledge[13]. This case study is one step to better preparing them for problem solving in industrial and technical settings.

Studies suggest that cases work best when they are used extensively during a semester[6]. This theory was applied in this instance since a single case was used throughout the full term with the goal of demonstrating that course concepts were not disconnected from each other. The case activities built on each other and, by the final case activity, students were required to apply their full skill-set of engineering science principles to the redesign of the FC cars. This impact would not have been as strong if the case had only been used once in the term or simply as a class discussion without hands-on assignments.

One of the main observations while implementing this case study was that the students struggled with the open-endedness of the case problem statement as well as the brief guidelines for each case activity. This was purposely done to encourage critical thinking but instead elicited a strong student response that they were not given clear instructions on exactly what they should do. This response is potentially because they are used to having detailed directions from their instructors in other courses and have made this an expectation in their education. The instructor wanted to challenge the students to use their high-order cognitive skills to apply engineering science principles to a real-world design; however, the students ended up struggling more with the open-endedness than with the engineering principles. Since the case activities tied in with concepts taught in the class, the instructor attempted to support the students by offering direction during lecture time on the engineering science principles that would help them complete the related case activity. With respect to the broader program objectives, a similar initiative was implemented in a first year mechanical engineering course the same year. Therefore, the next time that the second year pilot project course is offered, the new cohort of students would have this pedagogical experience so that they are better prepared to complete the fuel cell case study.

The strategy for this case study implementation was to teach relevant theory in the classroom that related to concepts being applied to case activities. Class discussions were used to clarify theory and promote analysis of application to the fuel cell car case study. The goal was to have sufficient support from classroom resources so that students could tackle the open-ended nature of the case activities. Although students were able to connect theoretical concepts to their design of the new chassis, it was concluded that they needed more guidance on what should specifically be included in their final design. This approach would ensure that students applied all relevant theory from the classroom to the case study and ease them in to their first main exposure to an open-ended problem. This approach would eventually not be needed since students would have gained necessary skills in a first year course with experiential learning components. The pedagogical goal of teaching open-ended problems, teamwork and concept application to second year students is still considered a necessary component of the course; however, the students were not used to this type of learning environment and would need more support with their first exposure. If this type of full-term, open-ended case study were to be used in subsequent courses for the same students, the instructors of these courses could start to expect more and more of these students' ability to handle open-ended problems.

Next steps

This case study was both newly developed and new to this mechanical engineering course. Therefore there was room for improvement; however, the objective of each case activity would remain the same. The first recommendation was for students to start the activities earlier in order for the case applications to align better with classroom theory and provide students more time to complete assignments. The highest priority would be to improve the hardware and activities to better streamline the experience. To further increase the impact of the model FC case study, it was recommended that this case be implemented in two other courses that are offered to the same group of students concurrently with the mechanical engineering course. It is not only important to demonstrate that concepts within a single course are connected, it is important to also show cross-course connections. There are analytical aspects of the FC cars that could easily apply to an advanced calculus and an electromechanical devices course.

Improvements to each case activity will also be implemented. It would have been ideal to see more groups use the successful design aspects of the Traxxas car in order to demonstrate that they could analyze an existing design and apply features to a different application. It would also be ideal to see students apply their recommendations from Case Activity 3. Increasing the amount of instructions and providing more specific requirements will force this outcome for future implementations and create a higher connection to classroom theory during weeks 2 to 7. It is also recommended that a broader design problem be created for Case Activity 5 so that students are required to apply knowledge from all concepts and previous activities to their final design. For the next course offering, the guidelines for this case activity will require students to use more than just one concept to their final design. This would keep the case study open-ended but still push students to utilize various course concepts, which is the ultimate goal of the case study and its activities.

The course analyzed the use of case studies in order to improve students' skills in handling open-ended design and applications of engineering science principles. This type of experience is drastically different from secondary education and should not be a single experience during undergrad (most commonly a fourth year design project/capstone project). The advantage of engineering case studies is that they provide a similar experience as a capstone project and are able to engage students in design thinking on a topic-by-topic basis[21]. The goal is to have these types of initiatives throughout the entire program; however, since the students struggled so much with open-ended problems, it is recommended to provide much clearer support in the classroom as this was their first exposure to this type of learning.

Conclusion

A case study was selected and implemented in a second year mechanical engineering science course. It was selected based on its potential for engagement, hands-on activities, general interest of the students, its scope, and its connection to course concepts. Although there was room to improve the implementation strategy of this case study, the overall objectives were met and the students were provided a valuable experience in experiential learning. They were also given the opportunity to apply engineering science principles and analysis to a current design problem. It is recommended that this type of implementation become more common in engineering education. In order to get students to truly accept this teaching method and the value of design with engineering science, case studies should be spread throughout numerous courses since this goal cannot be achieved in one lecture[22]. Furthermore, there is a need to start this teaching strategy immediately, beginning in first year courses[15].

This pilot project in the second year mechanical engineering course was part of a wider initiative to increase experiential learning at University of Waterloo and the learning outcomes were not just focused on a single course, but on program-wide learning outcomes. The long term goal is to provide students various design experiences throughout their undergrad so that they are better prepared for the workplace. It is important that this pilot project's case selection methodologies, results and implementation strategies are shared in order to act as a motivator to increase engineering design and science connections as well as encourage the improvement of open-ended problem solving skills in undergraduate engineering programs.

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