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Implementation and Impact of a First-Year Project-Based Learning Course

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Implementation and Impact of a First-Year Project-Based Learning Course

ABSTRACT

This evidence based practice describes the implementation of a two-quarter first-year engineering course, Introduction to Engineering, which provides an experiential learning experience to first year students focused on the engineering design process. Students complete two team based design projects, one per quarter, while using acquired skills in CAD, basic machining, and microprocessor programming to design, fabricate and test quadcopters. In addition, the course provides students with information on different engineering disciplines so they can make a more informed decision as to whether engineering is the right major. Student satisfaction was assessed at the end of each quarter. The impact of the course is evaluated through annual surveys to examine student motivation including student interests in engineering and the importance of teamwork.

Introduction

Advancement in science and engineering has become crucial to our nation in order to create jobs, optimize knowledge-based resources, and maintain a high standard of living[1]. With national engineering enrollment rapidly increasing, improvement and reformation in engineering education is vital in matriculating high quality, motivated graduates[2]. However, the majority of applicants have not been exposed to the field of engineering prior to high school graduation and have minimal hands-on science and engineering experiences in the K-12 curriculum. Furthermore, upon college entrance, engineering students often experience a discrepancy between classroom learning and practical engineering applications under many existing theory-focused curricula[3]. Consequently, this disconnect is often cited by industry who hire engineering students as interns or permanent employees. Moreover, with such curricula, students may be far less engaged and motivated. Studies have shown that, counter-intuitively, students who leave engineering due to lack of interest and engagement may be in good academic standing and perform well in core courses[4,5].

To battle the challenge of retaining and motivating students, engineering educators have developed various models ranging from a survey based introduction to different engineering disciplines, and the integration of project-based, problem-solving learning methods during the last decades. Such practices have successfully enhanced students' experiences during their first year and, hence, significantly improved student retention, motivation and satisfaction of the engineering curriculum[6].

We report on the initial and continuous development of a two-quarter first-year engineering course titled Introduction to Engineering, spanning Fall and Winter quarters, to provide students a basic understanding of the engineering design principles and various disciplines. In addition, the concepts of product development, project management, technical communication, teamwork and professional development are integrated into the course simulating "real-world" scenarios to better prepare our students for career paths in industry. An additional component focused on entrepreneurship was integrated in the course during the Winter quarter.

Course Development

To successfully formulate and engineer a freshmen program in 2012, we visited several renowned national first-year programs including University of Michigan, Purdue University, The Ohio State University, and University of Maryland. After detailed discussions with colleagues at these universities, we obtained a better understanding of the distinctive structure of each first-year program. After analyzing the benefits and challenges from these programs, we adopted the following practice: team-based and projected-based learning focused on engineering design with the integration of technical communications. Moreover, research also demonstrated that first-year students were more comfortable approaching upperclassman for advice in comparison to speaking with faculty or graduate students[7]. Accordingly, we were advised by all four existing programs to utilize undergraduate students as aids to the graduate teaching assistant or faculty in the first-year course. For this reason, junior engineering students were recruited as undergraduate assistants to support the course.

In 2012 and 2013, we selected an autonomous hovercraft design project developed by University of Maryland due to its highly interdisciplinary nature and its focus on product development. At the University of Maryland, the first-year engineering program was implemented as a one-semester (15 week) course. Due to the complexity of the project and related training, and the difference in academic calendar, we decided to convert and expand the one-semester course to a two-quarter long sequence with two credits assigned each quarter. This arrangement also allowed flexibility to integrate additional content such as instructions on engineering disciplines and entrepreneurship. Since the first-year course was not approved as a required class, but only as an elective for all engineering disciplines, students had to choose to enroll in the course. In order to increase the course enrollment in 2014, we decided to choose a project more relevant to technologies ubiquitous in popular culture, but still retained the core focus of design principles and product development. Inspired by the Amazon Prime Air delivery system, we decided to develop two related projects for implementation - remote control (RC) quadcopter and autonomous delivery quadcopter in the first and second term respectively.

To ensure the projects were robust and challenging enough for the incoming freshmen students, two student teams consisting of one graduate and two undergraduate students were assembled to design, build and test quadcopter projects prototypes over a six-month period. The graduate students were tasked with researching various quadcopter components and learned the necessary methods required to build the quadcopter. The two teams rendered different designs in SolidWorks and tested different sets of components to find suitable parts to be used in the course. After fabrication and trials of testing, a set of design specifications suitable for the course, such as size and power requirements, were formulated. Competitions were planned at the end of each quarter with the goals of having the shortest time for the quadcopter to traverse through a set course in the Fall quarter and the shortest time for delivering two objects based on color and distance recognition in the Winter quarter. We are in the process of developing additional discipline focused projects to be implemented during the second quarter due to suggestions from faculty to diversify projects to be more major specific.

Course Implementation

Since the course was not required, first-year students were informed and recruited through presentations during summer orientations and were enrolled on a self-selecting basis. Student enrollment increased dramatically since the initial piloting in 2012 as shown in Table 1 below. Approximately one third of the 2015 incoming freshmen engineering class chose to take the Fall course, demonstrating the successful expansion of the course with modified projects. On average, students spent 3.82 hours per week outside of classroom. Students who chose not to return for the Winter quarter mainly cited schedule conflicts or course overload, in surveys taken at the end of the Fall quarter. However, when asked whether students would advise the incoming freshmen to take the course, also in surveys taken at the end of the Fall quarter, the majority recommended the course as shown in Table 1 because of the experimental learning and team-based project.

	2012-2013	2013-2014	2014-2015	2015-2016
Fall Quarter (Enrollment)	109	160	223	253
Winter Quarter (Enrollment)	68	127	158	188
Students recommending incoming freshmen to take the course (%)	89%	94%	88%	91%

Table 1. Enrollment of first-year students from each academic year from 2012 to 2015

The Fall quarter course consisted of two one-hour lectures and one two-hour lab per week with lectures focused on technical topics, project management and team work, professional development, and various engineering disciplines. The technical aspect of the course covered a range of topics including engineering design principles, center of gravity, flight dynamics, stability, basic circuitry, and related fundamental topics necessary to design a quadcopter. From past student surveys of the pilot class in 2012, students concluded that the most important factor to the success of their project is team work. Thus, we emphasized the importance of project planning and team work throughout lectures. The teaching assistants also created a skit illustrating both dysfunctional and healthy team dynamics respectively. Student survey results on team work will be shown later in this paper.

In response to the number of undeclared engineering students in the class, five lectures featured faculty from each department presenting an overview of their major and current research within the department. Students with declared majors also benefited from these presentations as it gave them a basic understanding of other engineering disciplines and highlighted highly interdisciplinary emerging fields such as internet of things, clean energy, nanosystems, etc. This interaction with faculty engaged and encouraged students to explore research opportunities.

Similar to Fall quarter, Winter quarter consisted of one one-hour lecture and one two-hour lab per week. Topics including sensors, microcontrollers, programming and control were integrated into the course to satisfy the autonomous delivery aspect of the project. Additional lectures on technical and professional communications were included in the lectures to prepare students for technical presentations and interviews. As part of leadership development, three lectures on entrepreneurship were integrated into the course to allow students to contemplate on the business aspects of engineering. Students were requested to formulate in teams a business plan related to quadcopters. Moreover, multiple industry speakers and start-up founders were invited for class presentations regarding engineering design, career options, and cutting-edge research and technology to encourage interaction and participation of the first year students with industry leaders. We will report the results of incorporating entrepreneurship in future papers.

In each quarter, lab sessions were co-taught by TAs and technical staff. Each lab session had up to 24 students who were divided into teams with four to six students per team. The students were trained with necessary fabrication skills such as using hand tools, basic machining, woodwork, and basic electronics during the first four lab sessions in Fall quarter. SolidWorks, the required computer-aided design (CAD) software, was taught during lab sessions and students were not allowed to fabricate until a final design was submitted and approved by the lab instructor. According to the project requirements, other necessary training, such as programming microcontrollers, was incorporated in order to provide students enough knowledge to complete the project. During Winter quarter, Rapid Manufacturing/3D printing was also introduced as part of the course to enable students to experience alternative fabrication methods. To demonstrate project management skills, students were also required to submit Gantt charts to the lab instructor to depict the work breakdown tasks. A budget of $400 and $500 was given per team to build the quadcopters in each quarter respectively. A purchasing process was simulated as students had to submit a purchase request for desired components, which we supplied. A design report including all details of the project was required for submission at the end of each quarter.

Methodology of Assessment

A course evaluation was administered to the class for assessment each quarter. Student satisfaction was evaluated by rating the following on a scale from 0 to 4, where 0 is "very dissatisfied", 1 is "somewhat dissatisfied", 2 is "neutral", 3 is "satisfied" and 4 is "very satisfied":

- Course organization
- The effectiveness in significantly increasing knowledge in fabrication skills
- Lecture notes, syllabus, and supplied material
- Overall rating

The students were expected to develop a basic understanding of the engineering design process, the ability to use basic hand tools, CAD program and microcontrollers, and gain a broad view of different engineering disciplines. Though design process and teamwork were the primary foci of the course, we recognized that fabrication skills were also important for the purpose of project prototyping. Furthermore, we observed that students with prior fabrication experiences typically performed better during capstone design projects especially in device manufacturing. The course evaluation, given at the end of each quarter, asked students to self-assess their ability by comparing the following skills at the beginning and the end of quarter on a scale of 0 to 4 where 0 is "very little", 1 is "somewhat", 2 is "average", 3 is "moderate" and 4 is "high":

- Ability to design and fabricate a device (Fall quarter only)
- Ability to use simple hand tools (Fall quarter only)

- Ability to use CAD (Fall quarter only)
- Ability to list steps in the design process (Fall quarter only)
- Understanding of different engineering majors (Fall quarter only)
- Ability to program microcontrollers (Winter quarter only)

To further assess the impact of the course and its effectiveness in enhancing student motivation and understanding the importance of team work, an additional survey was given to students (pilot) who self-select into the first-year engineering course and another cohort (control) of students who were not enrolled in the course but volunteered to participate in the survey. This paper only showed results of the two cohorts we solicited in Fall 2012, and surveyed each successive year. The students were asked the following questions on a scale of 1-10 where 1 = "Not interested at all" and 10 = "Extremely interested" at the beginning of Fall quarter, at the end of Winter quarter, and then on an annual basis:

- Rank their current interest in majoring in engineering
- Rank their current interest in pursuing a career in engineering
- How important do they consider the non-Engineering courses (biology, physics, math, etc.) to current academic and career goals?

We also asked both the pilot and control groups to express their opinions on teams and learning by ranking their agreement with the following statements using the terms: strongly disagree, disagree, no opinion, agree, or strongly agree. The assigned corresponding score was 1 (strongly disagree) to 5 (strongly agree) respectively.

- Student teams produce better results than students working individually.
- Developing skills at working in teams is important to your future academic and career goals.
- It is more important to learn the concepts and methods of engineering than it is to receive high grades in engineering classes.
- I feel confident in my ability to succeed in an Engineering major.
- I feel confident in my ability to succeed in an Engineering career.
- My fellow students are useful resources that I may draw upon in my Engineering courses.

For statistical analysis, differences between two groups were tested by the Student's t-test. Differences were considered significant if $p < 0.05$.

Results and Analysis

As shown in Figure 1, student satisfaction using the quadcopter design project were measured by the average score of course organization and format, course effectiveness in increasing fabrication skills, effectiveness of lecture notes/syllabus/supplies materials, and overall rating using the scale described previously. 219 students participated in the Fall 2014 survey (indicated in blue) and 154 students participated in the Winter 2015 survey (indicated in red). Error bars were calculated based on standard deviation of the collected data. When asked whether the course should be recommended to incoming first-year students at the end of Fall quarter, 88% recommended the course, 9% refused due to the amount of work load, and 3% refused due to other reasons. Based on feedback from student evaluations regarding work load, most enjoyable and least enjoyable aspects of the course in Fall quarter, adjustments were made in Winter quarter accordingly to enhance the course. For example, to increase efficiency and reduce work load, both homework assignments and lab trainings were designed to be less theoretical and more practice based with direct application to the project. More demonstrations were incorporated into lectures to engage students. As shown in Figure 1, student experience improved for Winter Quarter relative to Fall quarter in the average score and also the standard deviation in all four course aspects.

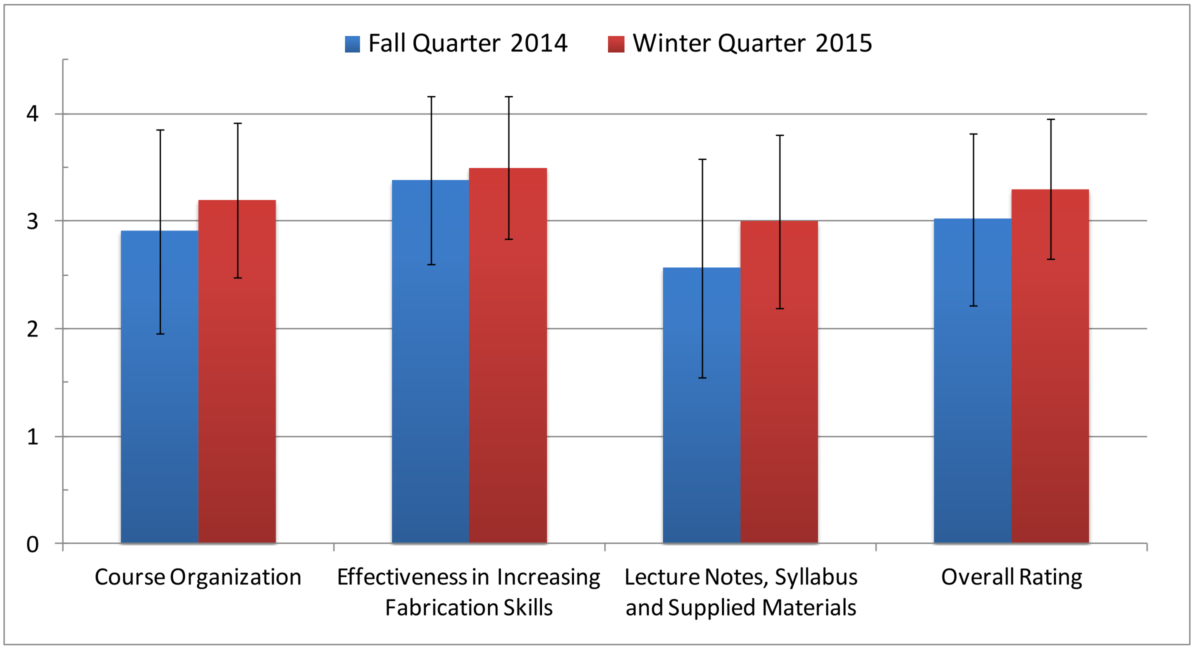

Figure 1. Comparison of course aspects between Fall of 2014 and Winter of 2015.

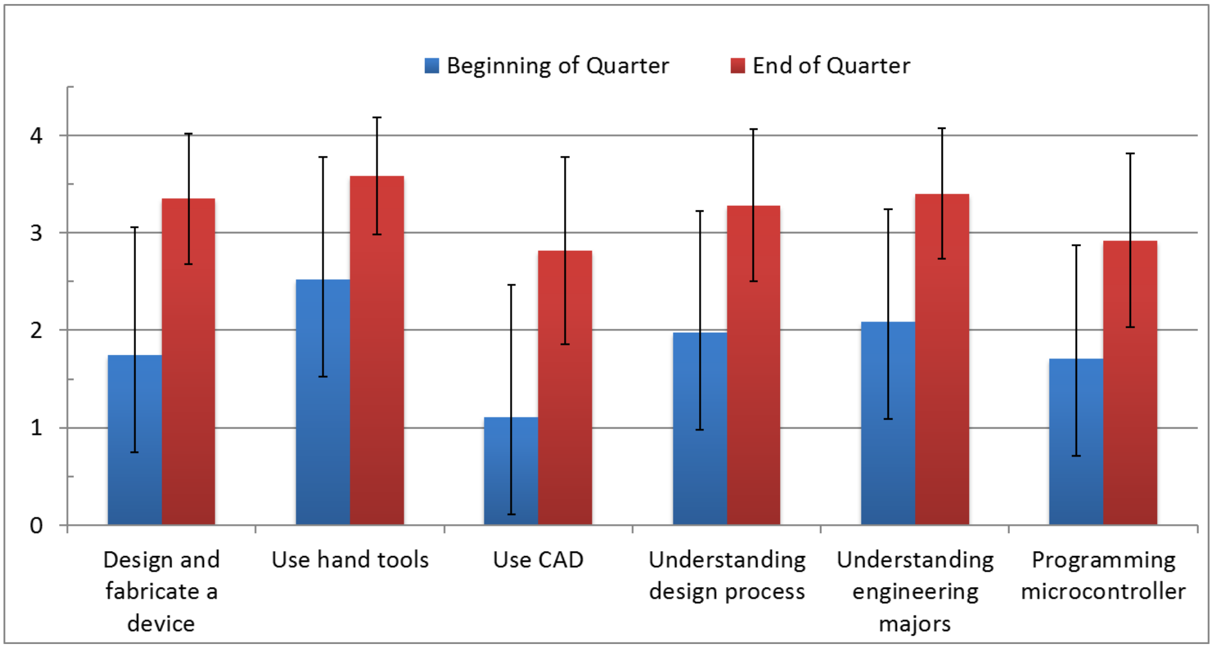

Figure 2. Student self-evaluation of learning outcomes.

In the same evaluation, students were also asked to self-assess their ability and necessary skills for completing the quadcopter project at the beginning and end of the quarter respectively. The survey results clearly demonstrated successful student learning outcomes on the assessed skills. As shown in Figure 2, higher average ratings with standard deviation at the end of the quarter (red) can be observed in comparison to the corresponding results at the beginning of the quarter (blue). Thus, the first year engineering course made a significant impact in understanding the design process, increasing student fabrication skills, student's ability to use CAD software, learning programming and understanding the differences among various engineering majors.

To assess the longitudinal impact on student motivation and student views on teamwork and learning, we solicited a cohort of 72 first-year engineering students (control group) who did not enroll in the pilot course in 2012. The same survey was also administered to 72 students enrolled in the pilot course (pilot group). The students in both groups were surveyed each successive year in the beginning of Fall quarter in 2012 (F12), the end of Winter quarter in 2013 (W13), the end of Winter Quarter in 2014 (W14) and the end of Winter Quarter in 2015 (W15). The students were asked the same questions as described previously in Methodology of Assessment. The control group with an average high school GPA of 4.01, and SAT Math score of 667, was an academically stronger cohort compared to the pilot group whose average high school GPA was 3.91 and SAT math of 605. In Table 2 and Table 3, the mean value with standard deviation were listed for the pilot and control group respectively. N represents the sample size which is the number of students who answered the particular question. P-value was also calculated to examine the differences between two groups.

Assessment Questions	Term	Mean ± Standard Deviation, N		p-value
		Pilot	Control	
Current interest in majoring in engineering	Fall, 2012 (F12)	8.71 ± 1.40, 72	8.29 ± 1.75, 72	0.12
	Winter, 2013 (W13)	9.03 ± 1.56, 66	7.54 ± 2.44, 35	**0.00032**
	Winter, 2014 (W14)	8.60 ± 1.54, 45	7.40 ± 2.98, 35	**0.022**
	Winter, 2015 (W15)	8.00 ± 2.85, 34	6.90 ± 3.30, 31	0.16
Current interest in pursuing a career in engineering	Fall, 2012 (F12)	8.65 ± 1.44, 72	8.26 ± 1.75, 72	0.15
	Winter, 2013 (W13)	8.95 ± 1.61, 66	7.88 ± 2.59, 34	**0.012**
	Winter, 2014 (W14)	8.27 ± 1.97, 45	7.46 ± 2.87, 35	0.14
	Winter, 2015 (W15)	7.82 ± 2.81, 34	6.71 ± 3.63, 31	0.17
Importance of non-engineering classes	Fall, 2012 (F12)	8.00 ± 1.66, 71	8.10 ± 1.87, 72	0.74
	Winter, 2013 (W13)	8.14 ± 1.60, 66	7.26 ± 2.16, 34	**0.022**
	Winter, 2014 (W14)	7.57 ± 1.77, 44	7.09 ± 2.29, 35	0.29
	Winter, 2015 (W15)	7.56 ± 1.74, 34	7.29 ± 2.30, 31	0.60

Table 2. Survey results on student motivation of two cohorts: students who took the first-year engineering course (pilot) and student who did not enroll in the course (control). Mean and standard deviation are calculated. N represents the sample size.

Statement	Term	Mean ± Standard Deviation, N		p-value
		Pilot	Control	
Teams produce better results than working individually	Fall, 2012 (F12)	4.07 ± 0.70, 71	4.04 ± 0.86, 72	0.74
	Winter, 2013 (W13)	4.38 ± 0.63, 66	3.60 ± 1.06, 35	**0.000015**
	Winter, 2014 (W14)	4.31 ± 0.63, 45	3.80 ± 0.87, 35	**0.0032**
	Winter, 2015 (W15)	4.18 ± 0.80, 34	3.94 ± 0.93, 31	0.14
Developing skills at working in teams is important to your future academic and career goals	Fall, 2012 (F12)	4.66 ± 0.48, 71	4.53 ± 0.63, 72	0.15
	Winter, 2013 (W13)	4.85 ± 0.36, 66	4.54 ± 0.70, 35	**0.0046**
	Winter, 2014 (W14)	4.67 ± 0.48, 45	4.54 ± 0.56, 35	0.29
	Winter, 2015 (W15)	4.74 ± 0.45, 34	4.65 ± 0.55, 31	0.47
More important to learn the concepts and methods of engineering than to receive high grades	Fall, 2012 (F12)	4.25 ± 0.77, 71	4.21 ± 0.84, 72	0.74
	Winter, 2013 (W13)	4.45 ± 0.66, 66	4.00 ± 1.08, 35	**0.01**
	Winter, 2014 (W14)	4.24 ± 0.88, 45	3.94 ± 0.94, 35	0.14
	Winter, 2015 (W15)	4.26 ± 0.75, 34	3.94 ± 1.08, 31	0.20
I feel confident in my ability to succeed in an engineering major.	Fall, 2012 (F12)	4.03 ± 0.80, 70	3.79 ± 0.92, 72	0.10
	Winter, 2013 (W13)	4.11 ± 0.88, 66	3.71 ± 0.99, 35	**0.044**
	Winter, 2014 (W14)	3.91 ± 0.90, 45	3.46 ± 1.17, 35	0.053
	Winter, 2015 (W15)	3.79 ± 1.11, 33	3.55 ± 1.29, 31	0.43
I feel confident in my ability to succeed in an engineering career	Fall, 2012 (F12)	4.03 ± 0.84, 71	3.86 ± 0.77, 72	0.22
	Winter, 2013 (W13)	4.20 ± 0.81, 66	3.74 ± 0.82, 35	**0.0087**
	Winter, 2014 (W14)	3.91 ± 0.76, 45	3.74 ± 0.94, 35	0.39
	Winter, 2015 (W15)	3.79 ± 1.07, 34	3.45 ± 1.21, 31	0.23
My fellow students are useful resources that I may draw upon in engineering courses	Fall, 2012 (F12)	4.30 ± 0.74, 71	4.07 ± 0.70, 72	0.063
	Winter, 2013 (W13)	4.48 ± 0.50, 66	3.97 ± 0.86, 35	**0.0025**
	Winter, 2014 (W14)	4.42 ± 0.66, 45	4.23 ± 0.60, 35	0.18
	Winter, 2015 (W15)	4.38 ± 0.60, 34	4.23 ± 0.67, 31	0.33

Table 3. Survey results of students' views on team and learning of the pilot and control groups. Mean and standard deviation are calculated. N represents the sample size.

As shown in Table 2 and Table 3, students in the pilot group maintained a higher mean in all survey questions than the control group in 2013, 2014 and 2015. The difference between the pilot and control group was significant ($p < 0.05$) at the end of Winter Quarter of 2013 when the pilot group completed the two-quarter first-year course. Students in the pilot group had a higher interest in the major and pursuing a career in engineering, compared to the control group. The pilot group also exhibited a better understanding of the importance of non-engineering courses. Similarly, in Table 3, students in the pilot group had a better appreciation of team-based learning, confidence in their ability to succeed in an engineering major and career, and a better appreciation of peer learning ($p < 0.05$), compared to the control group.

At the end of Winter Quarter, 2014, the pilot group still maintained higher "current interest in majoring in engineering" and a better appreciation of “teams produce better results than working individually"($p < 0.05$). However, the differences are not significant in all other comparisons ($p > 0.1$). The same results repeated for all questions at the end of Winter Quarter, 2015. The diminishing in differences may be attributed to the lack of project and experiential based learning in the sophomore and junior year for the pilot group. However, noteworthy is the fact that the pilot group was an academically weaker cohort based on incoming high school GPA and SAT math score. Thus, on the other hand, the course had a positive impact on the pilot group because the survey results demonstrated either higher or similar average scores compared to the control group over the three-year period.

Conclusion

This paper reports on a two-quarter first-year engineering course, developed and piloted in 2012 and successfully expanded annually to provide students an understanding of both the engineering disciplines and design process. Remote control and autonomous delivery quadcopter projects were completed by first-year students in teams in the Fall and Winter quarter respectively. Student satisfaction and student hands-on abilities were assessed through course evaluations. The course successfully enhanced student interest in pursuing engineering, and also had a positive effect on student views of team work and learning. The impact of the course will be continuously assessed through student retention, grades in physics, math, and other engineering courses. Additionally, experiential learning courses at the sophomore and junior level will be considered.

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