Effectiveness of Freshman Level Multi-disciplinary Hands-on Projects in Increasing Student Retention Rate and Reducing Graduation Time for Engineering Students in a Public Comprehensive University

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Abstract

This complete *Evidence-based Practice* paper describes the effects of hands-on multidisciplinary projects on the retention and graduation rates of engineering majors in California State University, Fullerton (CSUF), a public comprehensive university. The US national trend shows that undergraduate students in engineering majors have lower retention rates and take longer to graduate compared to other majors. Declaring an engineering major in the freshman year depends on the policies enforced at an academic institution. This case study is from CSUF, a public comprehensive university where the engineering programs have historically lower retention and 4-year, 5-year and 6-year graduation rates compared to the overall retention and graduation rate within the university. However, introduction of the hands-on project based "Introduction to Engineering" course resulted in a significant increase in 3-year retention and 4-year, 5-year and 6-year graduation rates compared to the students admitted to the programs prior to its introduction.

Motivation and background

The US national trend shows that undergraduate students in engineering majors have lower retention rates and take longer to graduate compared to other majors. The student retention rate depends on several factors including institution selectivity, race, ethnicity, and gender of student, all of which are tied to the student preparedness for undergraduate engineering education [1]. Some US institutions admit students as undeclared majors. These students declare their major either in the sophomore or in junior year. However, at other institutions, majority of the students declare their majors during their admission in the freshman year. Until the new "undeclared engineering" major was introduced in 2011, engineering and computer science students at CSUF were, generally, admitted with a declared engineering major. Those who were not certain about their majors were admitted as "undeclared". The undeclared students are generally advised by the university's central advising unit and often do not receive adequate discipline specific information to make a well—informed decision about the major they would want to consider. The inter-major and out-of-major transfer rates were high even among the declared first and second year engineering and computer science majors as many students were not familiar with the curricular details of the chosen majors. Moreover, engineering majors at CSUF are required to complete at least two semesters of calculus and a semester of physics courses before they start the first course in their engineering major. Records show that many students change their major during the first three semesters, very often, prior to taking their first engineering course, leading to high attrition rate in the first three semesters. A decision was thus made to add an "undeclared engineering" major and to design and offer an introductory hands-on projects-based course to introduce freshmen engineering students to various engineering disciplines and their sub-fields. As a result, a project based course, "Introduction to Engineering" was launched in fall 2010 followed by an "undeclared engineering" major in fall 2011 at CSUF.

Introduction to the project-based introductory course

The "undeclared engineering" major was introduced in 2011 to help students declare the major of their interest at the completion of their first year. Along with the addition of this major, a hands-on project based "Introduction to Engineering" course was introduced. Introduction to Engineering (EGGN 100) is a 3-unit freshman-level course and is offered in the fall semester of every academic year. Typically, two sections are offered with a target enrollment of approximately 40 students per section. The course mainly targets Engineering Undeclared (EGUN) students who have made a decision to pursue engineering, but are unsure about the specific engineering major that best suits their interests. As there are no introductory courses currently offered specific to each engineering discipline in the college, this course is designed to introduce all the four engineering disciplines offered in the college to incoming freshman.

The EGGN 100 course covers topics and hands-on projects from four engineering disciplines, namely, Civil and Environmental Engineering (CEE), Computer Engineering (CpE), Electrical Engineering (EE), and Mechanical Engineering (ME). The course is team taught by faculty from four different engineering disciplines, with each faculty member focusing on his/her respective area. In addition to receiving general information about each of these four engineering areas, students receive specific information pertaining to the curricular details of the Bachelor of Science (B.S.) degree program for each of these areas. Students also learn the basics about certain software tools that are commonly used in these majors. These include LabVIEW [2], MATLAB [3] and AutoCAD [4]. In addition, they take quizzes and complete mini-assignments using these software tools. The final exam includes topics covering all four majors. Overall, the course covers – a) Introduction to Engineering, b) Case histories in engineering projects – successes and failures, c) Introduction to CAD tools – AUTOCAD and basic drawing exercises , d) Virtual implementation tools in engineering – LABVIEW and Collection and utilization of data using the tool, e) Introduction to engineering analysis tools – MATLAB and problem solving, f) Introduction to Computer Engineering, g) Computer Engineering project, g) Introduction to Electrical Engineering, h) Electrical Engineering project, i) Introduction to Civil Engineering, j) Civil Engineering project, k) Introduction to Mechanical Engineering, and l) Mechanical Engineering project. The bulk of student performance evaluation in this course is through four team-based hands-on projects, one in each major area. Students work in teams to follow and implement specifications. Each project lasts a maximum of two weeks, including the explanation of relevant concepts and project specifications. The ideal target team-size is four students per team. However, this number has mostly varied between three and five students per team depending on the class composition and the availability of resources. The descriptions of the projects over multiple semesters are given below.

Computer Engineering (CpE):

The CpE project requires students to work in teams in order to use both software and hardware as per specifications. The specifications involve moving a robotic-kit, namely the Parallax "Boe-Bot" [5], to trace each letter of a given word successively within a specified duration on a predetermined grid. The Boe-Bot first traces the letter of the word and briefly pauses for a predetermined time. It then traces the next letter 'E', and so on until all the letters are traced and the Boe-Bot comes to a complete halt. The Boe-Bot kits are based on the "Basic-stamp"

microcontroller and are pre-assembled by the lab technician prior to the start of the CpE project. The microcontroller on the Boe-Bots can be programmed using the PBASIC language [6]. Isometric image and hardware system built for the project are presented in Figure 1.

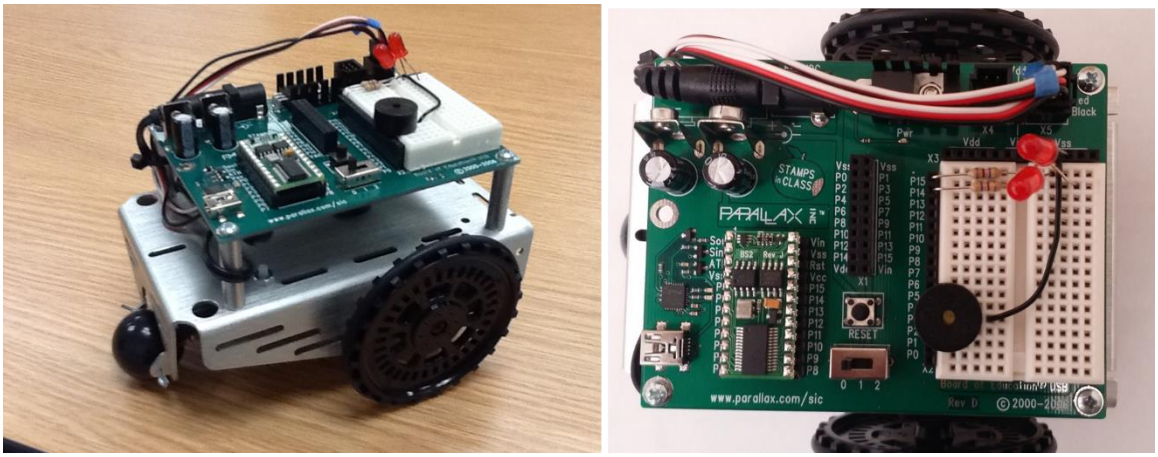


Figure 1: Isometric image and hardware system built for the CpE project.

Prior to beginning the actual project work, relevant microcontroller pins and their functionality are explained to the students. Programming concepts required to program the on-board microcontroller are also taught to the class. Students developed the following skills: a) using electrical pulses to rotate Boe-Bot wheels in clockwise and counter-clockwise directions, b) calculating the effect of program instructions on the duration of wheel rotation, c) writing a loop in a high-level programming language to control the timing of wheel rotation and the turning of the Boe-Bot's wheels, and d) working in teams. In some instances, the Boe-Bot project experienced issues with proper wheel alignment and other minor mechanical problems. Some students also expressed concerns about the level of satisfaction they experienced at the completion of the project. In addition, the two-week project completion time did not allow adequate time to address the issues related to moving parts of the board and suggested improvements. Since enhancing student motivation is an important consideration in this course, a different CpE project was introduced in fall 2016.

The fall 2016 CpE project required students to work in teams in order to implement a binary to hexadecimal number conversion on the 7-segment LED display of a Xilinx Spartan-3 FPGA (Field Programmable Gate Array) board. The students were provided with a program template written in the Verilog hardware description language. First, the students had to identify the hexadecimal equivalent of each 4-bit binary pattern. Next, the students had to create the appropriate binary codes that would result in the display of the desired hexadecimal number on the LED display. The students were then required to complete the Verilog program template. Upon successful compilation, the students were required to synthesize their design using the Xilinx Project Navigator software [7]. After this, they were required to transfer their design to the FPGA board using the Digilent Adept software [8] [9]. Additional details regarding the project specifications are: a) The left-most push-button on the FPGA board [10] is the ***reset*** button and b) User data is provided as an input in the form of a *nibble* (four binary digits or bits) using the right-most four slide switches on the FPGA board. When a given input nibble has been entered using these switches, the corresponding hexadecimal digit should be displayed <u>on the</u>

right-most 7-segment LED display of the FPGA board provided the reset button is not pressed, and c) If the reset button is pressed then the letter 'r' should be displayed on the right-most 7-segment LED display of the FPGA board, irrespective of input nibble provided at the slide switches. Through the project, students had the opportunity to develop multiple skills including: a) Counting using binary numbers, b) counting using hexadecimal numbers and identifying the relationship between binary numbers and hexadecimal numbers, c) determining the binary code required to turn on or turn off a specific LED inside a 7-segment LED display, d) compiling a Verilog program, e) using software to synthesize a design, f) implementing the design on an FPGA board, g) incorporating reset functionality into a design, and h) working in teams.

Civil and Environmental Engineering (CEE):

The CEE project focused on the design and implementation of a truss bridge as per given specifications: the truss bridge spans half a meter, is no more than 25 cm high, and is to weigh not more than 150 grams. The bridge is constructed entirely of spaghetti and 5-minute epoxy. The concepts of forces in tension and compression are applied in this project in order to complete the bridge. The students are given access to simplified bridge designer software, which allows them to calculate the internal forces within each member of the truss. The Euler buckling equation is explained to the students and, accordingly, they are encouraged to make compression members short and tension members long. A student assistant makes the compression members in advance (hollow tubes of spaghetti and epoxy with inner diameter of 1 cm) but the students are expected to lay out the bridge design, cut the members to length, and glue them all together. The students are ranked and graded based on how much load the bridge holds before failure. The load is derated by a square function if the truss is too tall and by a cubed function if the truss is too heavy. Students learn how to use bridge development software to calculate forces. Teamwork and project-management skills are also reinforced through this project. A sample bridge designed and fabricated by the students is presented in Figure 2.

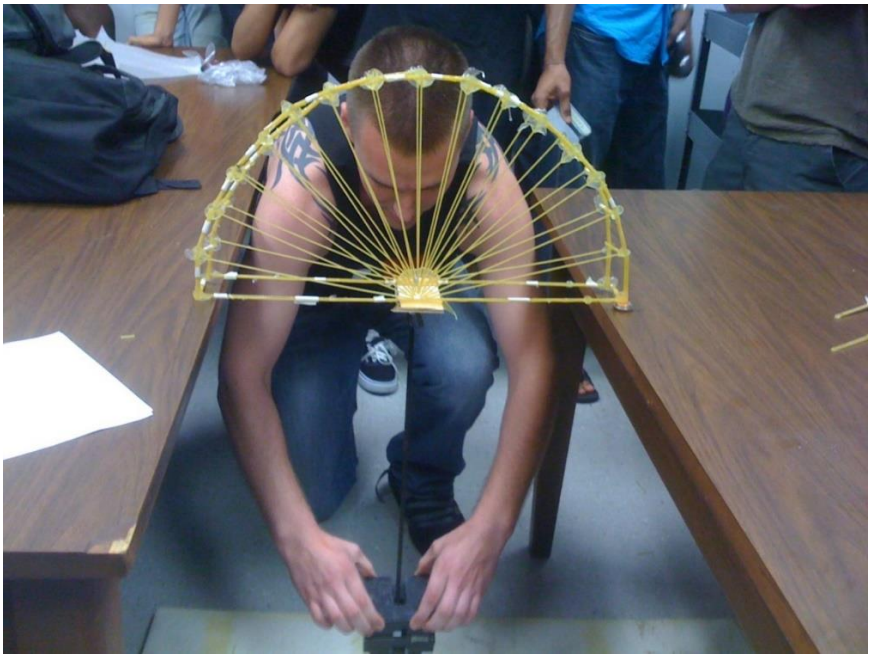


Figure 2: A spaghetti bridge being loaded as part of the Civil and Environment Eng. project.

Electrical Engineering (EE):

The EE project included the building of an audio amplifier and was aimed at teaching of specific concepts such as: a) contractual starting point for doing engineering, and b) specification tangibility (Measurable, Practicable, and meaningful to the end user); design concepts such as: a) using black-box functions to characterize a system (In this case: volume control->amplifer-> tone filter-> speaker), b) performance/cost trade-offs (e.g. speaker bass-response vs cost, muting of high-frequency response), and c) mathematical models to determine design parameters. (Used Ohm's law and MATLAB to calculate high and low frequency cut-off points.), implementation concepts, such as: a) graphic diagrams to describe a design (Schematics), b) common electronic components (Function, size, shape, and markings of ICs, resistors, capacitors, etc.), testing concepts, such as: a) objective tests – Objectively verified specifications with a signal-generator cell-phone app to measure frequency response and several go/no-go tests, and b) contractual end-point of engineering – Demonstrated the meaning of success in doing engineering. Skills enhanced by the project include: a) project management – Students created and held-to a schedule of objectives for each day, b) team collaboration – students worked in groups to complete the project, and c) technical report writing – using the given report outline and content for the Design and Implementation sections, students produced a complete project report. A sample circuit built by students for the EE project is presented in Figure 3.

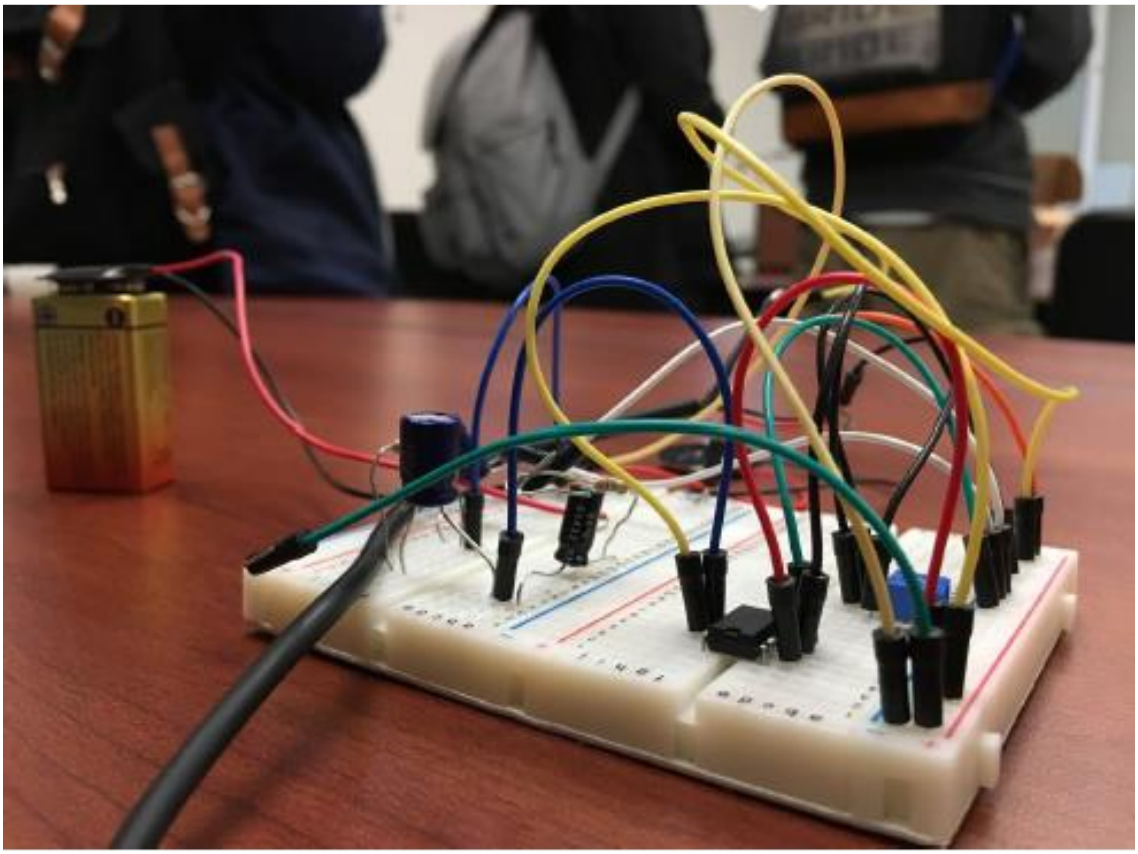


Figure 3: Sample circuit built by the students for the EE project.

Mechanical Engineering (ME):

The ME project involves the use of the engineering design process in order to build a wind turbine from everyday items. The goal is to lift a package of five pennies through a distance of 1 foot using nothing, but the stream of air from a stationary hair dryer running on high. Additionally, the problem is constrained to minimize the cost of the building materials while minimizing the speed of operation (which are weighted equally). For evaluation purposes, the projects are ranked based on this criterion to determine the most efficient design. Students test their designs in class and submit written documentation evaluating their results compared to the most efficient design. Students learn basic ME design skills through this project. They also develop a basic understanding about wind energy and wind turbines and how engineers can help solve global issues. Sample wind turbine designed by the students is presented in Figure 4.

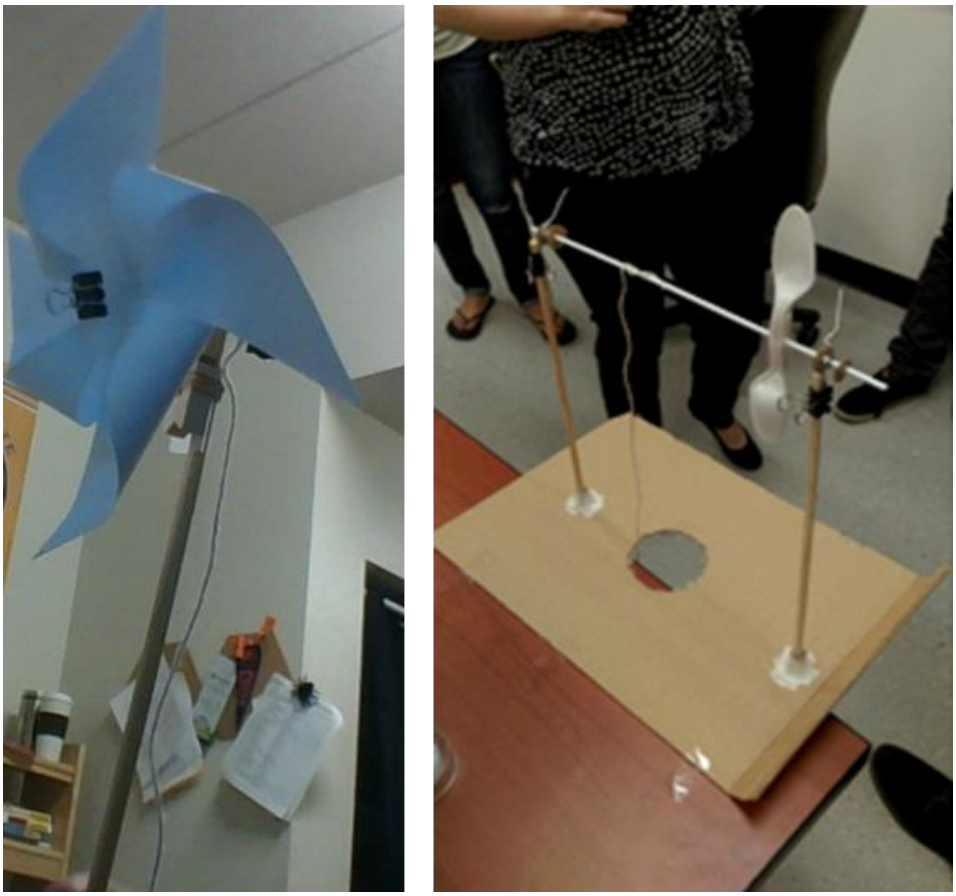
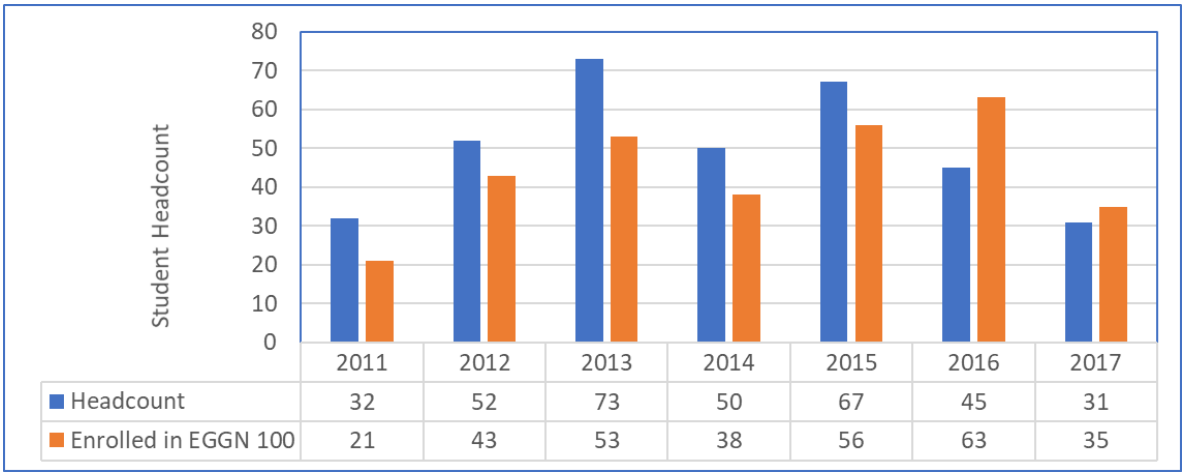


Figure 4: Sample wind turbines designed and fabricated by the students for ME project.

All of these discipline-based hands-on projects are simple, but challenging. Students get the opportunity to work collaboratively on the projects. The course is designed to include two important high impact practices [11] – a) collaborative assignments and projects, and b) first year experiences. The college tracks the progress of these cohort students to assess the effectiveness of the course in student success, specifically in increasing retention rate and reducing time to graduation.

Student Retention and Graduation Rates

Among the undeclared engineering majors, 66%, 83%, 73%, 76%, and 84%, on average, were enrolled in EGGN 100 in 2011, 2012, 2013. 2014 and 2015, respectively. There were more students in EGGN 100 in 2016 and 2017, mainly due to students who declared the major also took that course to double check the major they declared were appropriate for them, or not. Due to the attractiveness of the program, level of student support and the ease with which students are able to declare their majors in a timely manner, the number of undeclared majors increased gradually until 2016, as presented in Figure 5. For the students tracked over five years starting fall 2011, 79% students, on average, declared their major within a year. Typically, 64% of the undeclared engineering students declared a major in engineering or computer science. Among the students who declared their major in engineering and computer science, 2%, 7%, 22%, 8%, and 25% declared their major as computer science, computer engineering, civil engineering, electrical engineering, and mechanical engineering respectively, and of the undeclared engineering students who declared a major in engineering or computer science, on average, 75% were retained in their major and persisted into the 4th year.



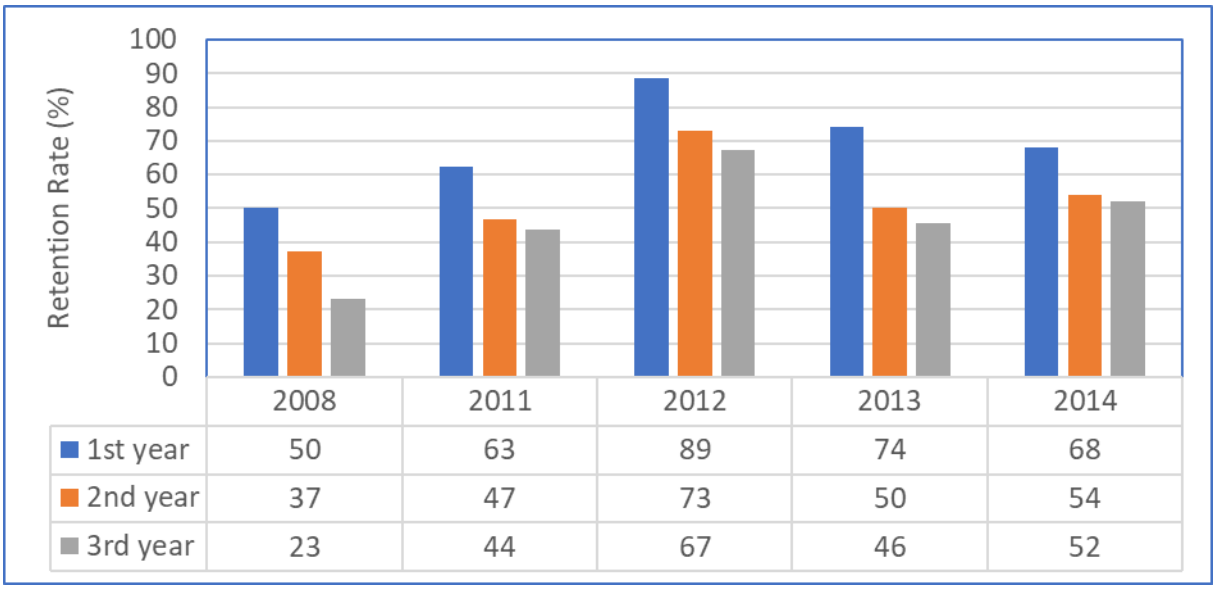
	2011	2012	2013	2014	2015	2016	2017
Headcount	32	52	73	50	67	45	31
Enrolled in EGGN 100	21	43	53	38	56	63	35

Figure 5: Total yearly headcount of the undeclared engineering majors and number of students enrolled in the EGGN 100 course in years 2011-2017

California State University, Fullerton is a public comprehensive university. Of the over 33,000 undergraduate students enrolled at this university in fall 2015, 10.4% were Engineering and Computer Science (ECS) majors. The 1st, 2nd, and 3rd year retention rates for students from the entire university for 2010-cohort were 84.9%, 78.2%, and 75%, respectively. Likewise, the 4-year and 5-year graduation rates for the cohort admitted at the university under this study in fall 2010 was 17.8% and 48.8%, respectively. However, the 4-year and 5-year graduation rates for the 2010 ECS-cohort were lower than 2% and 15%, respectively.

As mentioned earlier, the hands-on project based "Introduction to Engineering (EGGN 100)" course was added to undeclared engineering majors in 2011. Since then, the progress of the students with undeclared major have been regularly tracked. Prior to the offering of the undeclared engineering major, students who did not specify a major in engineering or computer science were admitted as "undeclared" by the university. However, the "undeclared" option for students interested in engineering or computer science transitioned from fall 2009 and phased out

in fall 2011. Therefore, for comparison purpose, the data pertinent to the 2008 cohort has been used in this study to compare with the cohorts enrolled after 2011. Figure 6 shows the 1st, 2nd, and 3rd year retention rates of the cohorts who declared engineering and computer science majors including undeclared engineering major. This shows that there is an average increase in 1st, 2nd, and 3rd year retention rates by 22%, 19%, and 30%, respectively after the introduction of EGGN 100. Shown in Figure 7 is the comparison of 1st, 2nd, and 3rd year retention rates of the undeclared engineering major cohorts who changed their major to an ECS or non-ECS major within the university. As can be observed in Figure 7, although the number of these students are very small comparted to the total enrollment in ECS, the experience students had in the *Introduction to Engineering (EGGN 100) course did show a positive impact on the retention rates in general. The* 1st, 2nd, and 3rd year retention of the cohort increased by 17%, 17%, and 30%, respectively even after changing to a non-ECS major.



	2008	2011	2012	2013	2014
1st year	50	63	89	74	68
2nd year	37	47	73	50	54
3rd year	23	44	67	46	52

Figure 6: Yearly first, second and third year retention rate of the undeclared engineering majors who declared engineering and computer science majors afterwards.

The data shows that with the introduction of the hands-on project based introduction to engineering course, retention rate and four-year, five-year, and six-year graduation rates of the undeclared engineering majors have noticeably increased. The student-self assessment survey results also show that the course, specifically the hands-on projects, helped the students to declare the major within their first year and develop their academic course plan. In this course, students get access to, and explanation of a four-year graduation road map as well as the course sequence offered in all four engineering disciplines so that students can plan ahead to take the correct courses in subsequent semesters. This enabled them to stay on track with the study plan even after declaring their majors. On the other hand, students who thought of engineering as one of their areas of interest, but subsequent to taking the EGGN 100 course decide that engineering may not be a suitable major based on their preparedness and interest, were able to change to a non-engineering major quickly without spending another year or two without declaring their major.

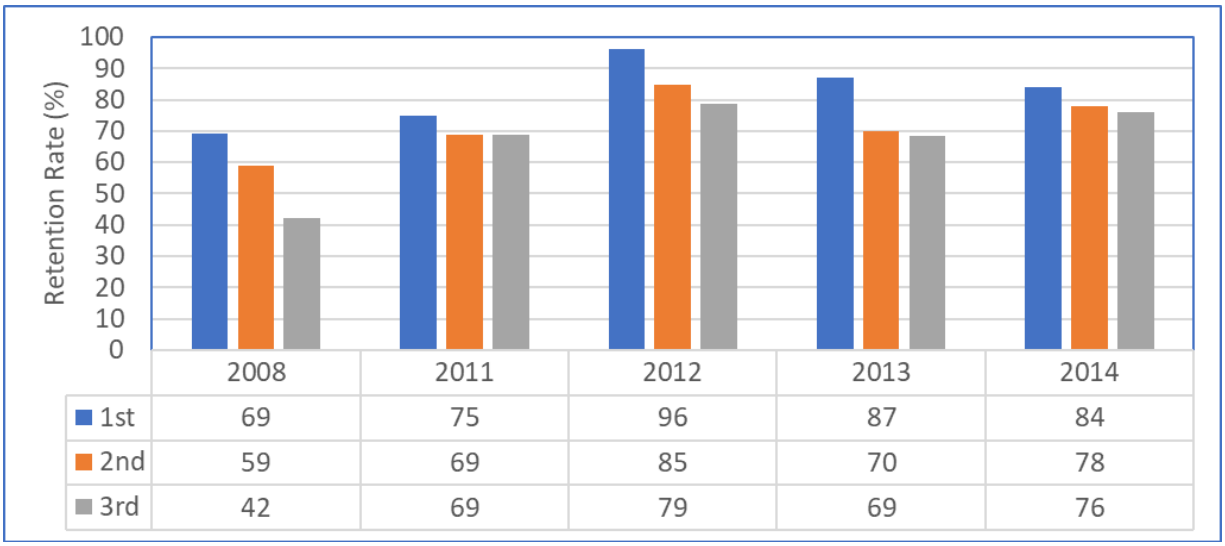


Figure 7: Yearly first, second and third year retention rate of the undeclared engineering majors who declared a major within the university at CSUF afterwards.

Presented in Figures 8 and 9 are the data pertaining to 4-year, 5-year and 6-year graduation rates of the undeclared majors who later declared their major within engineering and computer science or a non-ECS major within the university, respectively. The 4-year, 5-year, and 6-year graduation rates within engineering and computer science increased by 3% , 14%, and 15%, respectively compared to 2008 cohort. The increase in 4-year, 5-year, and 6-year graduation rates of post 2011 undeclared engineering majors within the university were 3%, 14%, and 23%, respectively compared to the 2008 cohort.

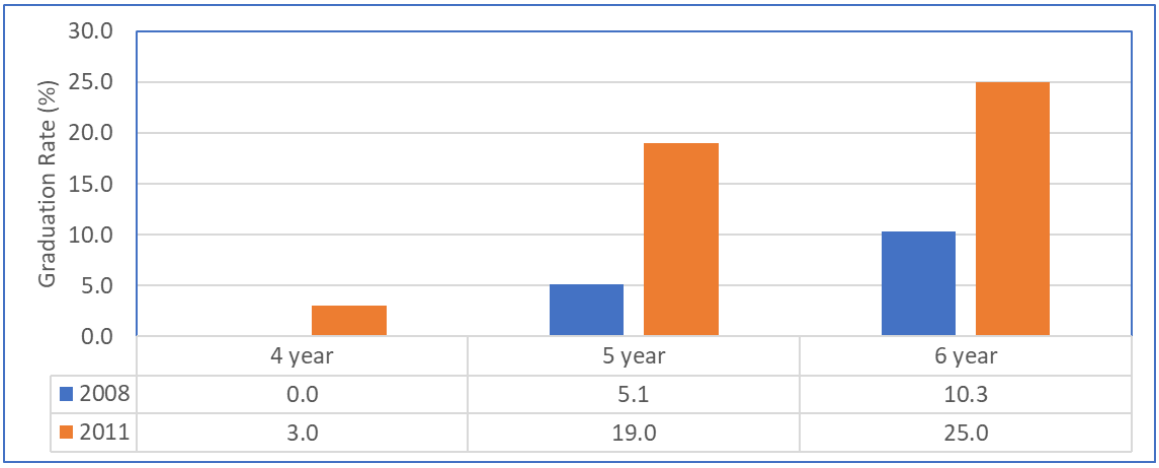


Figure 8: Yearly 4-year, 5-year and 6-year graduation rates of the undeclared engineering majors who declared a major within the ECS majors afterwards.

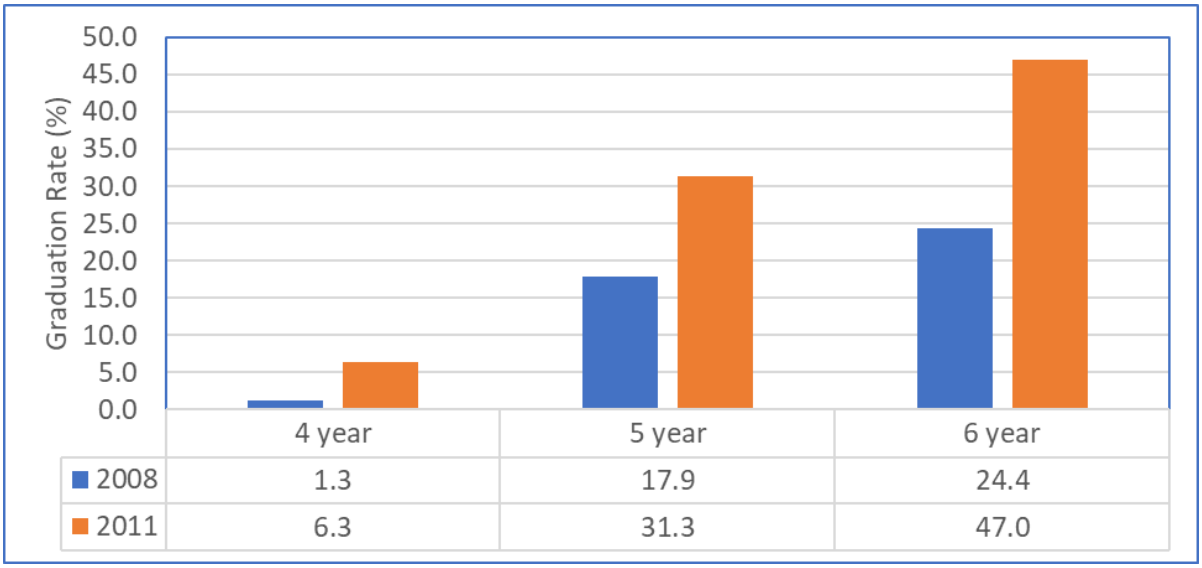


Figure 9: Yearly 4-year, 5-year and 6-year graduation rate of the undeclared engineering majors who declared a major within the university afterwards.

Discussion

As presented in previous sections, the EGGN 100 course has shown a significant impact in reducing the attrition rate and increasing the 4-year, 5-year, and 6-year graduation rates of undeclared engineering majors at C SUF. Retention and graduation rates show that the average 3rd year retention of the undeclared engineering majors after 2011 increased to 53% from the 2008 3rd year retention rate of 23%, whereas the post 2011 3rd year retention rate of the ECS majors increased to 50% in comparison to the 2008 3rd year retention rate of 32%. The retention rate increment for the undeclared engineering majors was higher than that for the ECS majors. This can be attributed to the effectiveness of engaging students through hands-on engineering projects and introduction of all engineering majors to the students, which in turn helped students to learn more about their major of interest. Likewise, the average 5-year graduation rates of the undeclared engineering majors after 2011 increased to 19% from the 5-year graduation rate of 5% in 2008, whereas the post 2011 5-year graduation rate of the ECS majors increased to 18% in comparison to the 2008 5-year graduation rate of 10%. Such dramatic increase in 5-year graduation rate can be attributed to student engagement and proper advising through the EGGN 100 course. It is expected that the 3rd year retention and 4-year, 5-year and 6-year graduation rates will further increase in future, as the positive effect of the hands-on project based course gradually shows fruition.

Summary and Conclusion

As most of the major courses in engineering and computer science programs are associated with both engineering and non-engineering prerequisite courses, and courses in these majors demand significant level of preparation, retention and graduation rates for engineering majors are lower compared to many other majors. Engaging students in hands-on projects, introducing and familiarizing them to various engineering disciplines, and assisting students with ideal study

plans towards the completion of the degree requirements and their graduation have proven to help students declare their major of interest early and focus on their study within the major. As a result, both student retention and graduation rates increase. Introduction of hands-on projects based *Introduction to Engineering* course for the undeclared engineering majors at California State University, Fullerton has facilitated significant improvement in the retention and graduation rates of students in engineering and computer science significantly.

Acknowledgments

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