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Improving Retention in Entry-Level Engineering Education by Adding Hands-On Courses of Clinics of Engineering in the First Year of Study

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Introduction

The four-year BS degree in Electrical Engineering (EE) program is well established at many universities. Since most of the EE programs were successful in previous decades, there were less changes in the lower-division courses and students are taking very few or not any courses from their major in the first two years of the program. But in recent years, universities are looking to improve their retention and completion rates and the first two years of study are playing a big role in these two parameters. In addition, the average number of new enrollments in undergraduate EE programs is flat or increased slowly nationwide, while the same number for the other programs increased [1]. On the other hand, many of the EE employers are looking only for highly skilled workers or the students with a graduate degree. Getting graduate degree will result in more years of study to get hired in Electrical Engineering.

The previous course plan in the EE program at California State University San Marcos was starting with math, science, and general study courses. Then the plan proceeds into basic circuit theory and component level studies. After the second year of study, analog and digital systems were started to be covered and eventually students were doing a senior design project to practice their knowledge by creating an applicable Electrical Engineering system. While the old approach was consistent with most of the other regional EE programs and it has a logical stackable development, it is postponing the engaging courses and practices of EE program to upper-division courses. Because of this, the lower division EE program was less interesting and ultimately lowered the retention rate. In a survey conducted among engineering programs at the California State University San Marcos, before implementing the new courses in this study, the EE students had 20% less sense of belonging to their program of study. While this was a known problem for the EE program, a closed-loop educational assessment and improvement was conducted to close the gap and relate students to their field of study as early as the first semester of study. In this new approach to the lower-division courses students will start system view courses and current prototyping circuits and tools were used to set up the laboratory experiments. The goals of this study were:

a) Integration of courses and providing a system view in the lower-division courses.

b) Improving retention and engagement in early years of study.

c) Closing the gap between lower-division and upper-division courses by practicing system view projects using prototyping system boards.

For all these goals a survey of the hiring industry was conducted in this study and the EE program at California State University San Marcos made related changes in its lower-division undergraduate courses. This study will indirectly help to improve the students' completion rate, hiring opportunity, and student motivation to participate in Electrical Engineering Club and

extracurricular activities. This paper will share the changes made in the undergraduate EE program at California State University San Marcos and the successful results of the new approach.

Background

Retention is one of the greatest ongoing challenges in STEM education, particularly in lower-division engineering students. A 2012 study showed that 40-50% of student's dropout of engineering programs in their first two years of study [2]. The challenge is exacerbated among underrepresented students, who are less likely to enroll in engineering majors and less likely to persist when they do [3]. According to Geisinger and Raman (2013), who surveyed literature in the field, a significant proportion of engineering students leave because the engineering educational system has failed to:

1) show them that the engineering endeavor is profoundly human,
2) make relevant the key scientific, mathematical, and engineering principles needed for mastery of engineering,
3) show that engineering is within reach of their abilities,
4) capture their imagination and fascination,
5) provide a welcoming atmosphere.

They concluded that six broad factors drive students to leave engineering: classroom and academic climate, grades and conceptual understanding, self-efficacy and self-confidence, high school preparation, interest and career goals, and race and gender. They also noted that studies suggest that retention can be increased by addressing one or more of these factors [3].

In order to address the factors that persistently cause so many students to leave engineering, and to develop a lower-division curriculum that will engage and retain Electrical Engineering majors, particularly those from underrepresented groups, California State University San Marcos, proposes to implement this study to improve retention. This paper will address two of the retention issues that Geisinger and Raman noted—classroom and academic climate and interest and career goals—by creating a sequence of lectures to connect the classroom topics into real world applications in three hybrid lower-division Electrical Engineering courses for students at the California State University San Marcos. The new courses are seeking to change students' perspective about engineering and help create a more inclusive environment by improving the existing Introduction to Electrical Engineering course and developing two new courses: Electrical Engineering Clinics I and II. In these courses students from different educational backgrounds will learn the fundamentals of Electrical Engineering through a hybrid model that allows them to learn concepts and skills through hands-on activities. In addition to the lessons, which will draw from introductory topics in engineering, the courses will utilize online material and hands-on in-class activities to offer courses directly related to the students' major and required skills in their first year of study. The first course in this sequence was offered at the California State University San Marcos and it successfully attracted students from other majors as there are many students in their first year of study who want to learn more about engineering and engage in this field. The second course is currently being offered to complete the achievements of this proposed sequence of courses. This study showed that the suggested courses are providing the missing link between existing lower-division courses for the major, which focus almost exclusively on science and math prerequisites,

and Electrical Engineering jobs and requirements in local industries, thereby connecting students' coursework with their future careers.

The New Approach

As part of the new educational paradigm, the system view approach to teach lower-division courses of the EE program was studied and the related courses are being developed. Current industry trends in Electrical Engineering, such as renewable energy systems, wireless communications, electric cars, Integrated Circuits, etc., are advanced technologies and difficult to be studied in the first or second year of study. Introducing these concepts requires state-of-the-art course design and new teaching methods to enhance student interest and improve the quality of the curriculum and the extent of its content. Fortunately, as new technologies have emerged, so have new approaches with the potential to transform what and how students learn, and consequently to address the factors behind the attrition of underrepresented students from engineering majors [4]. In particular, software is replacing hardware and there are more simulations and advanced graphical programming for EE programs.

Additionally, there are low-cost prototyping circuit boards that students can start experimenting with in their first semester of study, if not in high school. With these new additions and the current trend of students learning the basics of computer programming in their first year of study, it is possible to teach the concept level systems and finish projects as early as the first semester of study in engineering education. Recent studies have shown that project-based learning is more effective in promoting active learning, rather than bottom up traditional teaching which starts from component level [5], [6], [7]. Moreover, concept level problem-based learning has proven invaluable in helping students who struggle to connect what they are learning to their lives [8], [9]. For these reasons, problem-based learning is starting to be used in different courses of engineering and sciences, such as in Computer Science and Mechanical Engineering courses, and is considered one of the best environments for learners [3], [10]. This model of education is an example of a top down level approach in which students start with the definition of the problem in a specific course, then they learn the details and components required to solve the problem. For this project, we are using the same problem-based learning model to create an EE program. It begins with a concept and system modeling approach, integrating the required courses in the EE program, connecting the lower division courses to the real-world applications, and improving retention.

First-generation college students, such as 53% of California State University San Marcos Students, need to be able to relate their education to the real world. In order to address the factors that persistently cause so many students to leave engineering, as well as to develop a lower-division curriculum that will engage and retain Electrical Engineering majors, particularly those from underrepresented groups, this project proposes to implement Top-Down-Top approach in Electrical Engineering to fulfill the educational requirements of engineering industry and to improve retention. This project addressed two of the retention issues that Geisinger and Raman noted: classroom and academic climate and interest and career goals [11]. If students choose to study Electrical Engineering, but do not see and learn interesting topics related to their major in the first two years of coursework, they may lose interest in the field and degrade the academic climate. If they do not feel any sense of belonging to the program, they may not participate in the

classroom and ultimately change majors. Furthermore, engineering education is known as an intense major; If students do not know about the opportunities they will have after graduation, they may be drawn to fewer challenging majors that offer less lucrative job opportunities.

Our proposed changes tackled these issues through two approaches: 1) Teach students the skills they need to explore compelling topics in EE as early as their first semester, rather than just the science and math prerequisites that currently dominate the lower-division curriculum, and 2) Motivate students by showing the higher-level job opportunities and variety of career possibilities that they will have after graduation if they persist in the major. We accomplished this by creating a sequence of three lower-division EE courses and using real world projects in the rest of EE courses, for example wearable electronics, robotics, wireless communication, etc. These courses are more computer-based and in some cases, a microcontroller board, a PLC, or a data acquisition box will be used to create a complete system. Students are learning the basics of programming languages in their first year of study and some students may learn this at high school level. Then in the EE courses, they are practicing professional software skills related to EE program and computer programming are covered intensely to model, simulate, or solve EE problems and projects.

The new courses are seeking to change students' perspective about and identification with engineering and help create a more inclusive environment by improving the existing *Introduction to Electrical Engineering* course and developing two new courses: *Electrical Engineering Clinics I and II*. In these courses, students from diverse educational backgrounds are learning the fundamentals of Electrical Engineering through a hybrid model that allows them to master the concepts and skills via interactive software assignments to model the hardware and ready hardware and circuits to implement the applications, such as Arduino, Raspberry Pi, NI Mydaq, PLC systems, etc. The course material is tracking what students have mastered and provides a learning environment that addresses each learner's need. It also allows students to "visit" and tour Electrical Engineering workplaces with both virtual field trips, and if possible, real-world field trips, in order to connect their learning to real-world applications.

This paper is addressing the work in progress after developing the course of *Introduction to Electrical Engineering*. The course was introductory, and the enrollment was open to nonmajor students too. To make the curse engineering Elegoo^{TM} UNI R3 was used for laboratory practices. Since the course was offered remotely due to Covid-19 pandemic, every student received a multimeter, an Analog Discovery II, and required wires and components to conduct experiments. The activities started with basics of voltage and waveforms to help students to know and to measure electrical parameters. Then the practices moved to basic resistor circuits and circuit laws. After students got familiar with making circuits, the course continued toward digital circuits with teaching about basics of binary numbers, Boolean functions, and laboratory practice with logic gates. The goal in learning basic topics was to prepare students for working with Arduino board provided in Elegoo^{TM} box. The input output interfacing with Arduino was offered by using the existing library of simple experiments by Arduino. Students were learning step by step to make changes in their code to achieve the goals of experiment and become familiar with the functionality and coding of microcontrollers. Activities started with sending command to LEDS and getting input from switches then improved to the projects using seven segments, spearker, and servo motor.

Results

While this is an ongoing project, the first course in the sequence of three courses proposed in this study, was offered in fall 2020. A comparison of students' retention rate in lower-division programs of Electrical Engineering at California State University San Marcos, shows a 14% increase between the fall and spring semester enrollment, before and after offering the new courses in this study.

Another important result of this project was the survey of students who study Electrical Engineering. Electrical Engineering students didn't take any course in their major in the first year of this study in academic year of 2019-2020 and they took a course in their major in the second year of this study in the academic year of 2020-2021. Figure No.1 shows an improvement in sense of belonging to their major in the students of Electrical Engineering before and after implementation of changes in this study. The first column in Figure No.1 shows a 6.07 out of 10 for the mean value in the sense of belonging for the students in academic year of 2019-2020.

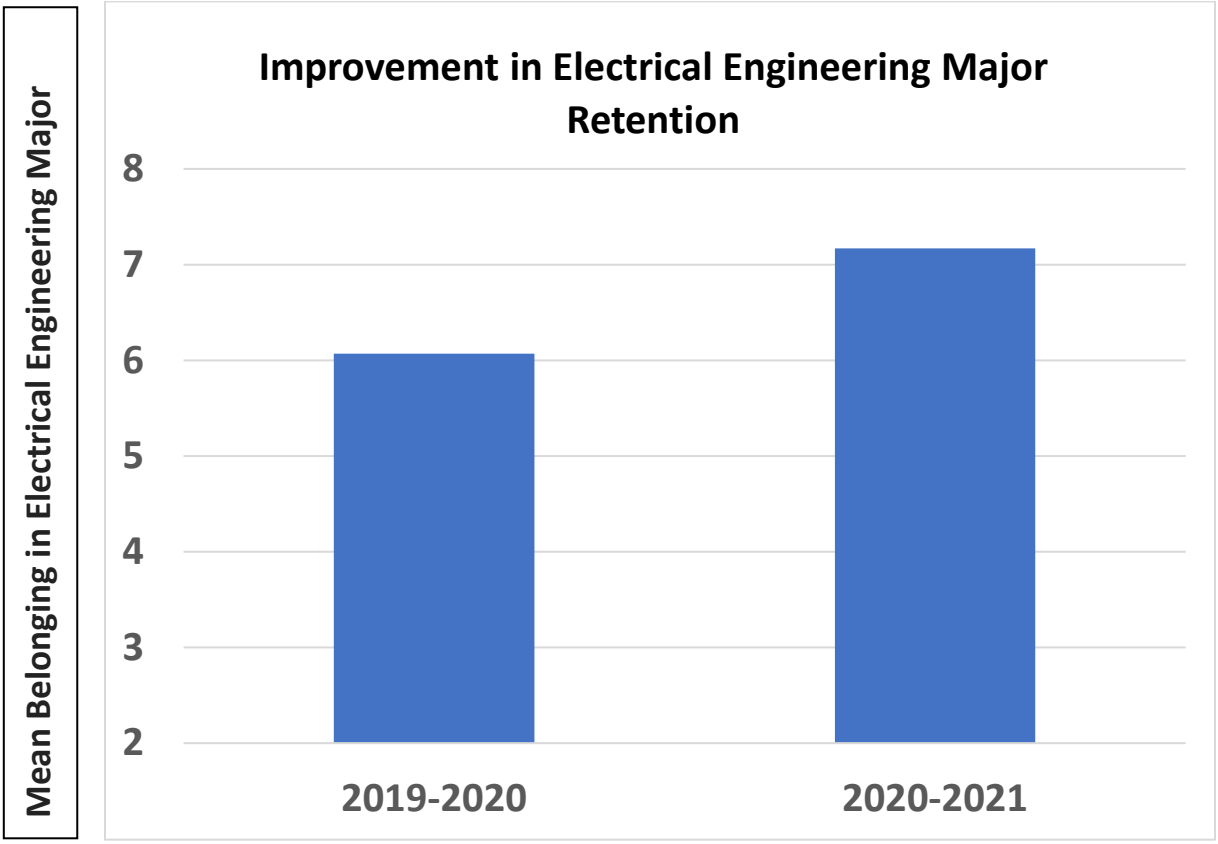

Figure No.1, A comparison for the sense of belonging among the students of Electrical Engineering in academic year of 2019-2020 and 2020-2021. It shows an improvement in sense of belonging during this study [12].

The second column in Figure No.1 shows the sense of belonging to their major between the students of Electrical Engineering after EE students take the first course developed in this study. This figure shows 7.17 points out of maximum 10 for the mean values of belonging among the students of Electrical Engineering major. It means an improvement after offering the first course in this study. It is estimated that offering the second and the third courses in this project will further close this gap and improve the engagement and retention in lower-division programs. This project has another objective of improving the students' participation in activities such as IEEE Chapter and Electrical Engineering Club to create a robust sense of belonging to the college and university. While these activities are ongoing and popular at every university, the impact of taking the new sequences of courses on the student participation in Club activities is not covered. In the next fall semester, the school will open for in person teaching and practices and there will be a better opportunity to expand this study and measure any other objective. Sense of belonging in this study was measured by surveying the 26 Electrical Engineering enrolled in the program and it may have up to 5% error.

The engineering team at the California State University San Marcos are currently preparing more system views and introductory lessons to offer for the next academic year. The future work in this project will be focused on the integration of courses and improving completion rate among students.

Conclusion

In this paper a new sequence of courses for the lower-division undergraduate program in Electrical Engineering is reported. The new courses are adding a system view approach to lower-division courses and the title of courses are Introduction to Electrical Engineering, Clinics of Electrical Engineering I and II. The hypothesis was to help improve the students' sense of belonging and retention. While there were no specific text books and course materials to teach the targeted courses in this study, the engineering team at the California State University San Marcos completed the first course of this ongoing project and achieved the objectives of this study. It was possible to improve the sense of belonging among EE students by 11%. It is obvious that offering the proposed courses provided a successful path for students learning retention. In future this project will report achievements of offering the other courses suggested in this project.

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