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Impact of a First and Second Year Culminating Experience on Student Learning in an Electrical Engineering Curriculum

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Abstract

This paper presents findings from an impact study of a lower division student experience within an undergraduate electrical engineering curriculum. This experience, culminating in the second year of the curriculum, is integrated across multiple first and second year courses and includes elements commonly found in senior-level capstone project courses. An introductory programming course utilizing an embedded platform is the first course in the sequence. The final course in the sequence requires students to design, build, and test an autonomous mobile robot. Through a series of milestones, students systematically complete both the hardware and embedded software tasks required for the project. The final milestone involves an industry-sponsored event where the entire student cohort participates in a robot competition.

For a number of years, anecdotal evidence has suggested that the course sequence has significant positive impacts on student experience throughout the curriculum. It has been postulated that this experience results in significant knowledge gain, reinforces their decision to pursue a career in electrical engineering, and builds camaraderie amongst the student cohort. A study was conducted to better understand these potential impacts. Part 1 of the study analyzed grades in the project course sequence and compared them to another course sequence that also occurs in the first and second year of the curriculum. Part 2 was a survey in which students and recent graduates were asked a variety of questions regarding the impact of the experience on other courses, on their competency in curricular outcomes, and on their overall experience within the academic program. This paper describes the course structure, the current implementation which has evolved over many years of offerings, and presents results indicating its impact on student performance and learning in the remainder of the curriculum.

Introduction

The electrical engineering program at Milwaukee School of Engineering (MSOE) has for many years offered a required course sequence in embedded systems to its undergraduate students. The sequence begins with an introductory programming course taught in the first year and culminates in the second year with a project-based course where all students create an autonomous robot using an embedded microcontroller. An industry-sponsored student competition with the entire cohort is held and awards are provided to the winners.

Over the many years of offerings, anecdotal evidence has suggested that the benefits of the course sequence are multi-faceted. It is believed that student development of technical skills pays dividends in later coursework, particularly in other project-based courses such as senior design. Further, it is believed that students benefit in non-technical ways such as helping them identify with the electrical engineering profession, thus validating their choice of academic study. Because the course sequence occurs during the first and second years of the curriculum, there is an opportunity to study these potential impacts on the student cohort at later points in the curriculum. A two part study was conducted which sought to explore and measure the impact of the course sequence.

Project-based learning, which is also related to problem-based learning, is an inductive educational methodology[1] where learning is accomplished by applying skills to a project or problem. The advantages of this type of learning includes positive impact on content knowledge, increased levels of student engagement, improved critical thinking, and improved problem solving[2].

The use of project-based courses in an engineering curriculum is not new. Many engineering programs meet EAC of ABET General Criterion 5 requirements through the use of project-based senior design course(s). Project-based design courses have been shown to have positive impact on professional skills post-graduation[3]. However, such courses occur at the end of the curriculum and the ability to study the impact on the curriculum as a whole is not possible.

Oregon State University demonstrated the use and benefits of a robotics project-based course early in an electrical engineering curriculum[4,5] with the TekBot platform. Since that time other engineering programs have implemented and studied the impact of project-based robotics courses early in the curriculum. As an example, the United States Naval Academy has researched the benefits of using a project-based robotic project in introductory courses[6]. This research indicates positive results in the student's engagement, but did not examine the impact the course had on future courses in the curriculum. Additional research at Rose-Hulman Institute of Technology studied improvement in the understanding of "a more realistic mode of their future work place demographic"[7]. The results, while positive, where mostly anecdotal in nature.

Finally, research on the benefits of cohort in engineering education is limited[8], but indicates the importance of cohort development on the development of a positive "attitude" towards engineering.

This paper presents the findings of a two part impact study. The remaining sections describe the course sequence and how it has developed over many years of offering, Part 1 of the study involving an analysis of student grades, Part 2 of the study involving surveys of current students and recent graduates of the program, and a discussion of the results.

Course Sequence Description

The student experience consists of a three course sequence. The first course, *EE1910 Introduction to Embedded Systems Programming*, introduces the concepts of structured programming, basic microcontroller functionality and development tools. This course is usually taken in the winter quarter of the freshman year. The programming concepts are taught in the context of an embedded system utilizing the Arduino Uno platform and the Arduino development environment. The course is structured with three hours of lecture and a three hour lab each week for applying the concepts learned in class. Students are expected to understand and be able to utilize the basic programming concepts to solve engineering problems.

The second course, *EE2920 Embedded Systems*, covers the basics of microcontroller architecture, peripherals commonly found in microcontrollers, and interfacing to external sensors and control devices. This course is usually taken in the fall quarter of the sophomore year. The same Arduino Uno platform is used, but a transition is made to the Eclipse Integrated Development Environment (IDE) and the C programming language. The course is structured with three hours of lecture and a three hour lab each week for applying the concepts learned in class. The sensors and output devices used in the lab sessions are primarily those that the students will need to use in the final course in the sequence. This gives them experience interfacing to these devices and reduces the workload somewhat in the final course. Students should gain an understanding of how the microcontroller and its peripherals function, and should be able to apply this knowledge to create solutions to engineering problems.

The final course in the sequence, *EE2930 Systems Interfacing*, provides an opportunity for the students to apply everything they have learned in the preceding courses to the solution of an open-ended design problem with constraints. This course is usually taken in the winter quarter of the sophomore year. The students buy a kit of parts and raw materials to supplement the kits from the previous courses. The end product, an autonomous robot, is specified with a minimal set of constraints, but it is up to the students to determine how to satisfy those constraints. For some, this is the first exposure to building something. The course has two hours of lecture and three hours of lab each week. The lecture time is used to review some of the concepts and devices, as well as introduce new concepts like Finite State Machines for implementing behavior, and creating test plans. Weekly milestones help motivate the students to make progress toward the final goal. Lab notebooks are required for documenting the design process. Instructors use a common grading scheme across all sections of the course. The culmination of the course is a required robot competition involving the whole student cohort. The emphasis in the competition is on participation. This competition has a corporate sponsor, and takes place during an Open House for prospective students.

Impact Assessment Study – Part 1

The first part of the impact study examined courses grades from students that have registered for and completed the embedded course sequence over the past four years. A total of 204 full-time and part-time student records were examined. Of that number, 104 graduated from the program, 88 are still active in the program and on a path towards graduation, 1 student switched to a related program and 11 did not graduate and are no longer active in the program. Removing the 12 students from the 204 possible results in a persistence rate of nearly 94% for students that successfully complete this course sequence.

Course grades were collected for each student record. The grade system at MSOE consists of "A", "AB", "B", "BC", "C", "CD", and "D." These letter grades were mapped numerically into 4, 3.5, 3, 2.5, 2, 1.5, and 1, respectively for analysis.

Plots showing grade distribution where compiled for EE1910, EE2920, and EE2930. The differences in grades, or delta, between EE1910-EE2920, and EE2920-EE2930 were also computed for each student record. The grade and grade delta distributions for the embedded course sequence are shown in Figures 1 and 2, respectively.

The data are an aggregate of four years of course offerings. In any given year, multiple sections of each course were offered, taught by several different instructors. In EE1910 and EE2920, the grading rubrics and student performance expectations are determined by the individual instructor, and therefore can vary from offering to offering. The aggregate data provides some degree of averaging which lessens the impact of individual instructor bias. In EE2930, a common set of course milestones and grading rubric are used across all course offerings, both of which have remained relatively stable over the four year data set being considered. Therefore, the EE2930 grade data is largely instructor independent.

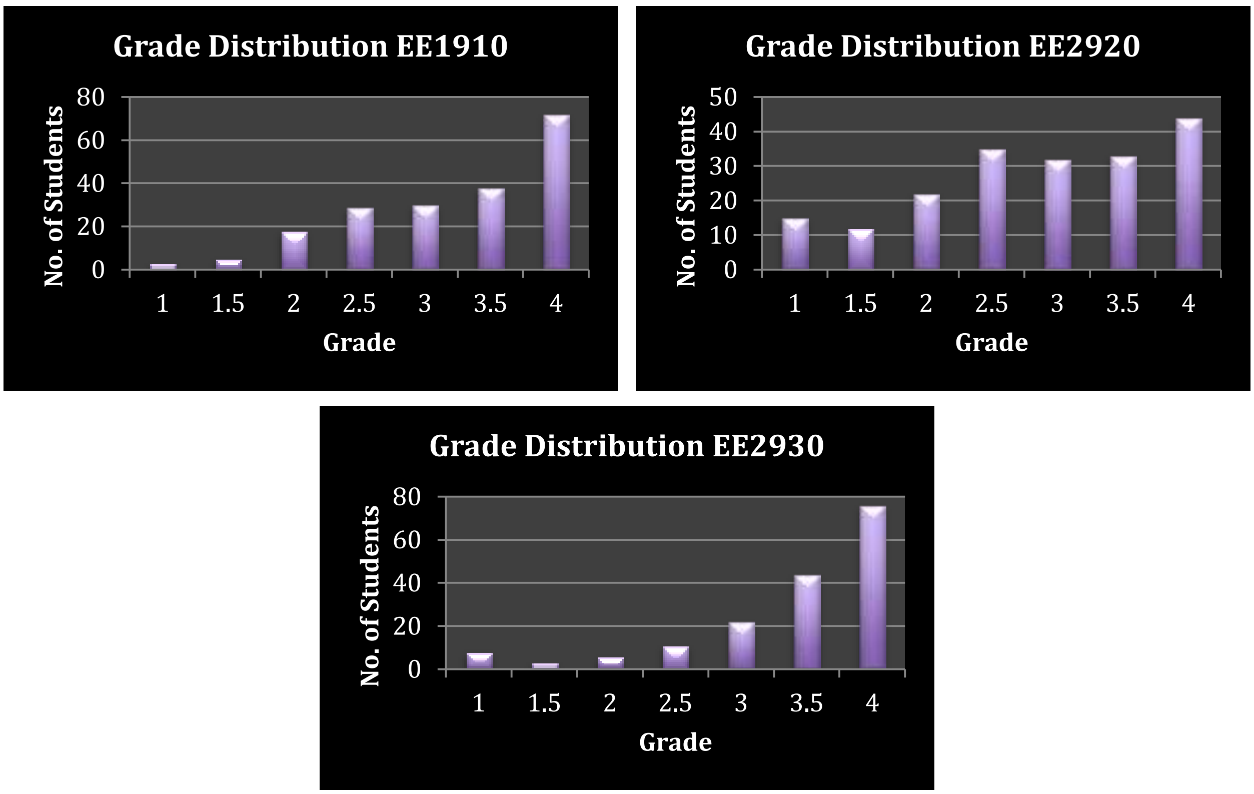


Figure 1: Grade distributions for embedded course sequence

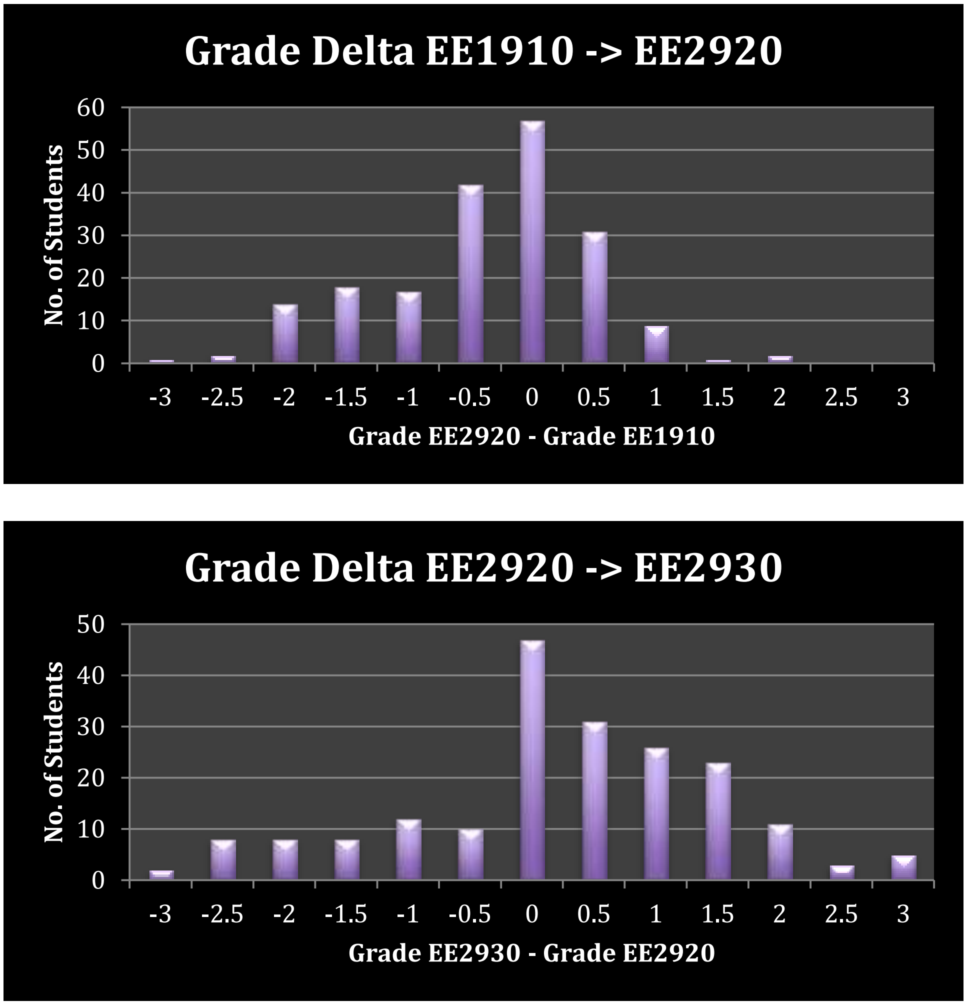


Figure 2: Difference in grades between courses in the embedded course sequence

As a means of comparison, course grades from a three course electrical circuits sequence (EE2050, EE2060, and EE2070) were also collected for each student record. The first course in the circuit sequence, EE2050, is taken in the spring quarter of the freshman year, one quarter after EE1910. The remaining courses in the circuit sequence (EE2060 and EE2070) are taken in the fall and winter quarters of the sophomore year which are the same quarters for EE2920 and EE2930. Therefore, the circuits sequence and the embedded sequence share similar structure and timing within the curriculum.The delta grades for the circuit sequence courses, EE2050-EE2060 and EE2060-EE2070 are shown in Figure 3.

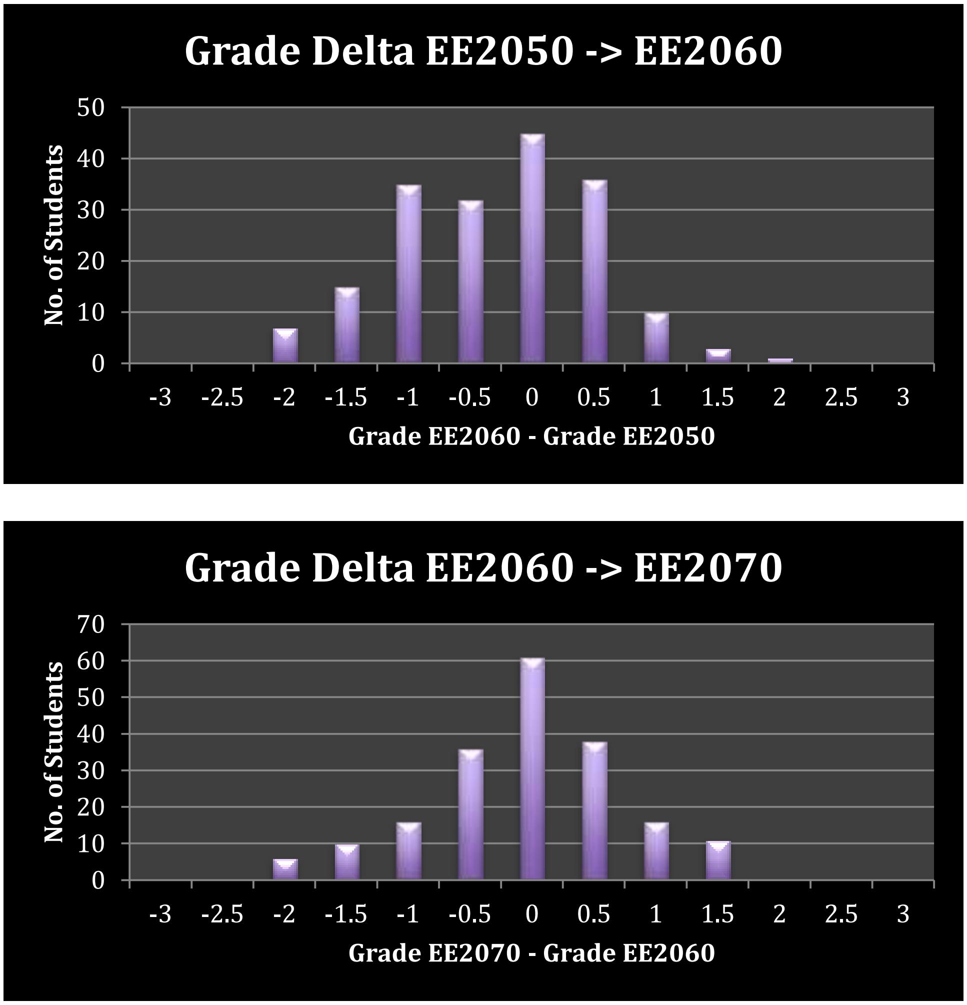


Figure 3: Difference in grades between courses in the circuits course sequence

The data show several interesting results. There is a shift downward in grade distribution from the first course to the second course but then a greater shift upward from the second to third course in the embedded sequence (Figure 2). The circuit sequence course grades also exhibit a shift downward from the first to the second course, however, there is little grade shift between the second and third courses in the circuits sequence (Figure 3).

The authors speculate that the shift downward between the first and second course of each sequence is the result of increased requirements and rigor in the sophomore level courses as compared to freshmen level courses. However, what is interesting to note is the shift upward between the second and third course in the embedded sequence. We believe this shift indicates something fundamentally different about the embedded sequence, which may include factors such as an increased level of student engagement and perceived value associated with the course sequence. Part 2 of the impact study sought to identify such factors.

Impact Assessment Study – Part 2

The second part of the impact study was conducted using a survey distributed to 81 current full-time students who had successfully completed the embedded systems course sequence. The survey was also distributed to 91 recent graduates of the electrical engineering program. The survey instrument was designed to identify trends in the following three areas:

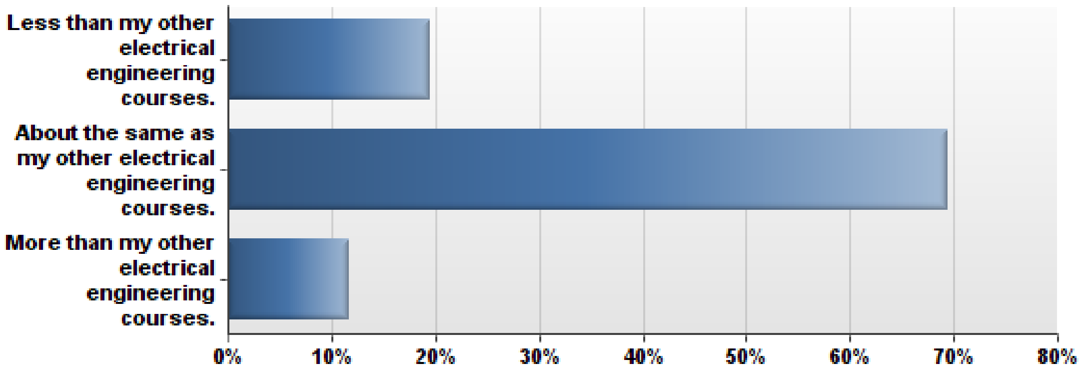
1. student perception of workload in the course sequence
2. student perception of the value added by the course sequence
3. roles the course sequence may play in student identification as an electrical engineer

The survey results shown below were aggregated from the 26 responses provided by current full-time students in the program. The response rate for the current full-time students was 32%. The response rate from recent graduates was significantly lower and the results have not been aggregated into the numerical data. However, in most cases the responses provided by the recent graduates are consistent with those provided by current students. Where appropriate, specific comments from recent graduates have been included.

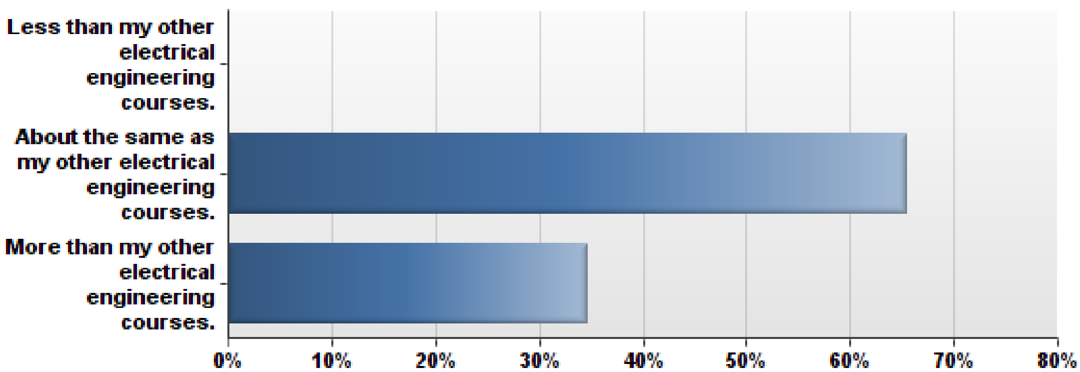
The first series of questions asked respondents to compare the workload in the embedded course sequence to other electrical engineering courses. Figure 4 shows the results for each of the three courses.

The data shows that in comparison to other electrical engineering courses, students perceive an increasing workload as the course sequence progresses. In particular, more than 70% of students reported that the workload in EE2930 exceeds the workload of other electrical engineering courses. This is a significant result particularly since survey participants are currently taking either junior- or senior-level courses within the program. The survey included an open-ended question in which students were asked to share thoughts or feelings regarding the work load. The following responses provide further insight into student perception and experience:

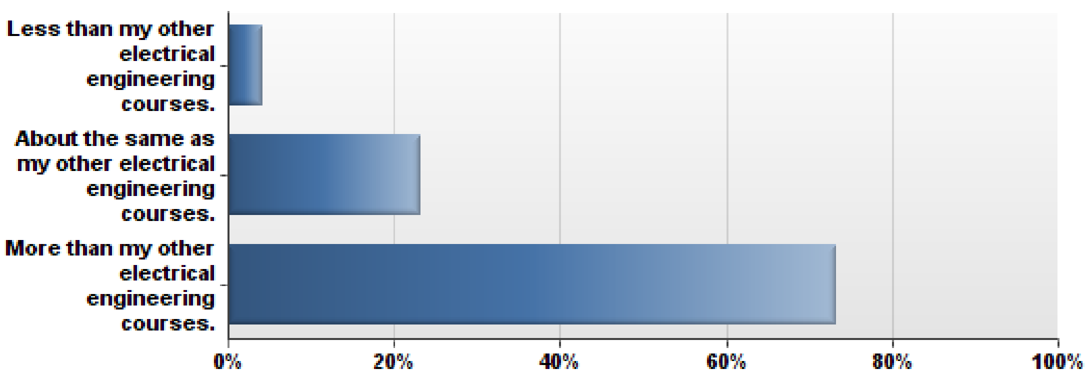
> *"Many of us were easily working up to 10 hours per week on the robot. It calls for dedication."*
>
> *"2920 was only a bit more. 2930 took over my entire quarter."*
>
> *"EE2930's workload exceeded the other 12 credits of classes, combined."*
>
> *"The work load was a lot for the middle class, but the work done in the middle class allowed for a smaller work load in the final class"*
>
> *"The work load is dependent on how much work the student puts into the previous courses. Strong focus on 1910 and a even stronger foundation in 2920 really helps the workload for 2930."*
>
> *"… a significant portion of the work loads for the quarters during which they were taken, though part of that may have been as a function of my interest and desire to work on such projects."*



(a) EE1910



(b) EE2920



(c) EE2930

Figure 4: Student perception of course sequence workload.

A response from a recent graduate reiterates the final comment above:

> *"My workload for EE2930 was higher not necessarily because there was more to do. It was because it was so much fun that I wanted to spend more time working on the project."*

From the numerical data and survey responses, we have confirmed that the course sequence, particularly the second and third courses, demand a significant portion of the student's time. As one might expect, the open-ended responses indicate a range of satisfaction with the increased workload. Several students cited dissatisfaction, particularly as it impacted their other coursework. Many responses also suggest that some students choose to invest more time because they enjoy the project. A somewhat revealing set of comments show that many students recognize that knowledge gained in the earlier courses plays a significant role in the workload of EE2930.

The second series of survey questions was designed to investigate student perception of the value and impact of the course sequence. One question asked respondents to rate the value of the courses to their overall education in the program in comparison to other electrical engineering courses. The results are shown in Figure 5.

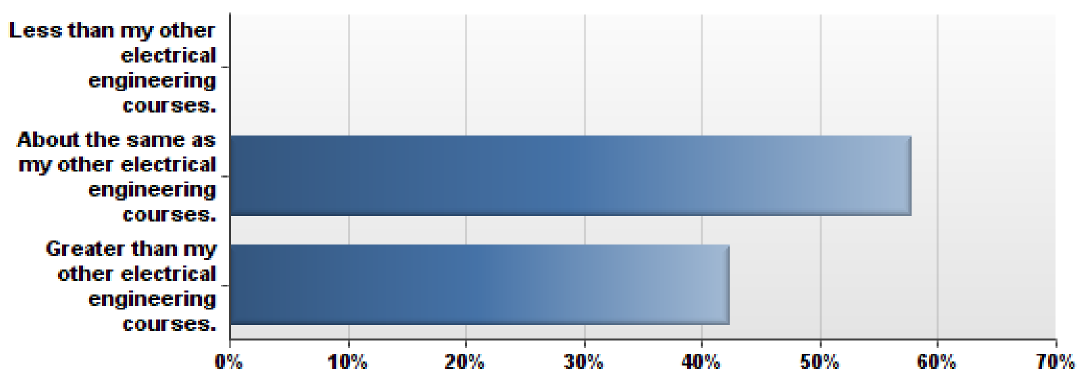


Figure 5: Student perception of course sequence value and impact.

We believe it is significant that in excess of 40% of our current students see the value of the course sequence as greater than other electrical engineering courses. A follow-on question asked students to rank, using a 5-point scale with 1 as least impactful and 5 as most impactful, the impact the course sequence had in developing their competency in ABET Criterion 3 Student Outcomes (a), (b), (c), (g), and (k) as well as their overall creativity. The results are shown in Table 1.

Table 1: Course sequence impact on competency development

Area of Student Competency	Mean	Variance
a) Your ability to apply knowledge of mathematics, science, and engineering.	3.4	1.2
b) Your ability to design and conduct experiments, as well as to analyze and interpret data.	3.9	1.3
c) Your ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.	3.8	1.5
g) Your ability to communicate effectively.	3.0	1.7
k) Your ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	3.7	1.3
Your overall creativity.	3.7	1.2

The data indicate that students recognize the role courses played in developing their competency, particularly in (b), (c), (k), and their overall creativity. Once again, the small numbers of responses received from recent graduates are consistent with these findings. An open-ended question asked respondents to identify other courses in which they benefitted from having taken the embedded course sequence. Two items dominated the responses. The first commonly cited sequence was the program's digital logic sequence which has a very similar three course structure in which the final course is project-based. The second commonly cited sequence was the Senior Design sequence. In particular, the following responses illustrate the scope of the relationship to Senior Design:

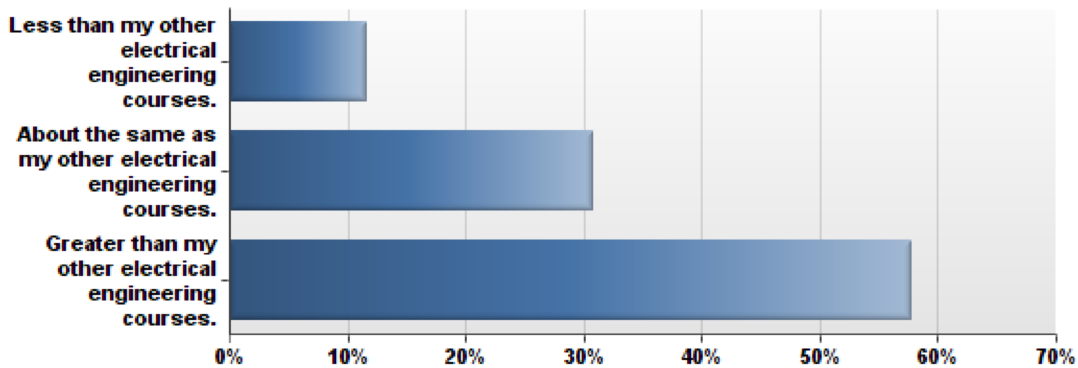
> *"…in senior design, the general knowledge of interfacing with embedded devices was invaluable to completing our project"*

> *"the design process principles I learned in the object courses of this survey, were further developed and continue to be in senior design"*

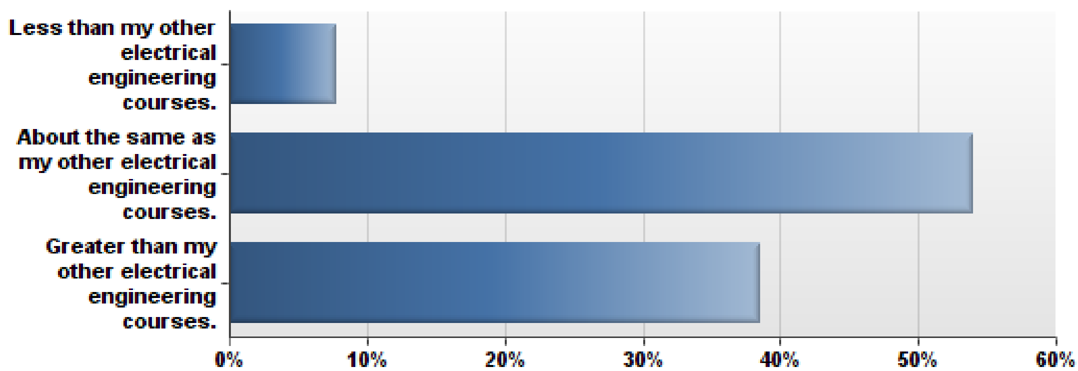
This particular open-ended question also elicited responses in which students spoke of value beyond just other coursework. A general theme throughout the responses was that students saw significant value in deep learning of a programming language, debugging, and troubleshooting concepts. The responses described a wide variety of ways in which the course sequence concepts were applied in other contexts. One particular response illustrates the potential impact:

> *"This class first taught me how to think like an engineer, and help me to learn how to attack problems in other classes."*

The final series of survey questions sought to assess the degree to which the course sequence impacts the student's own identification with electrical engineering. Respondents were asked to assess the degree to which the course sequence promoted their identification as both an electrical engineering student at our institution and, more generally, as an electrical engineer. The results are shown in Figure 6.



(a)



(b)

Figure 6: Course sequence impact on identification (a) as an electrical engineering student, and (b) with the discipline of electrical engineering.

The survey results show that the course sequence plays an important role in promoting student identification. We feel that the >55% response of "Greater than my other electrical engineering courses" is of particular significance, and confirms our hypothesis that the course sequence plays an important role in forming our student cohort during the second year. Student comments to the corresponding open-ended question included:

> *"I strongly felt it really helped me grasp what an engineer would do…a defining class…"*
>
> *"After finishing I had a great sense of belonging and accomplishment"*
>
> *"…completing it successfully gives an impetus and confidence as an engineer"*

Conclusions

The results from these two studies indicate that the workload for the final course in the sequence, EE2930, was greater than their other courses and their additional effort was reflected in an upward shift in grades as compared to the preceding course. We speculate that this increase is due to the increased engagement and ownership that students take in designing and building their own robot. The student's clearly know ahead of time that meeting milestones will result in higher grades. All of the milestones are published on the first day of class, and one could speculate that a student content with a "B" or "C" would produce only the required effort for that grade. However, this is not the case. Students, on the average, expend greater time and effort. Perhaps, EE2930 is the first class in the program that has an open-ended problem, with no single, pre-determined solution. Therefore, the solution is theirs and theirs alone. Another contributing factor may be the friendly competition with their peers' robots. Whatever the underlying cause, the survey results clearly indicate that this course sequence strongly supports their identity as an electrical engineer in the program. It's no wonder that the persistence rate of students that complete the course sequence is nearly 94%!

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