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Sophomore-Level Curriculum Innovation in Electrical and Computer Engineering

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Dimitrios Peroulis received his PhD in Electrical Engineering from the University of Michigan at Ann Arbor in 2003. He has been with Purdue University since August 2003 where he is currently leading a group of graduate students on a variety of research projects in the areas of RF MEMS, sensing and power harvesting applications as well as RFID sensors for the health monitoring of sensitive equipment. He has been a PI or a co-PI in numerous projects funded by government agencies and industry in these areas. He has been a key contributor in two DARPA projects at Purdue focusing on 1) very high quality (Q>1,000) RF tunable filters in mobile form factors (DARPA Analog Spectral Processing Program, Phases I, II and III) and on 2) developing comprehensive characterization methods and models for understanding the viscoelasticity/creep phenomena in high-power RF MEMS devices (DARPA M/NEMS S&T Fundamentals Program, Phases I and II). Furthermore, he is leading the experimental program on the Center for the Prediction of Reliability, Integrity and Survivability of Microsystems (PRISM) funded by the National Nuclear Security Administration. In addition, he led the development of the MEMS technology in a U.S. Navy project (Marines) funded under the Technology Insertion Program for Savings (TIPS) program focused on harsh-environment wireless micro-sensors for the health monitoring of aircraft engines. He has over 170 refereed journal and conference publications in the areas of microwave integrated circuits, sensors and antennas. He received the National Science Foundation CAREER award in 2008. His students have received numerous student paper awards and other student research-based scholarships. He is a Purdue University Faculty Scholar and has also received ten teaching awards including the 2010 HKN C. Holmes MacDonald Outstanding Teaching Award and the 2010 Charles B. Murphy award, which is Purdue University's highest undergraduate teaching honor.

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Abstract

Historically, the early years within an electrical and computer engineering (ECE) curriculum have largely focused on electrical circuits. A new sophomore level ECE course and laboratory which provides students with a breadth of foundational ECE concepts, frequent opportunities to engage with the instructor and peers in a problem solving learning environment, and both formative and summative assessment approaches was introduced by Prof. Peroulis and a committee at the School of Electrical and Computer Engineering at Purdue University. This paper focuses on understanding the impacts of introducing such a course into the curriculum. The course covers the three main pillars of Electrical Engineering: Electromagnetic fields and waves, Circuit theory and linear systems, and semiconductors and micro/nano-technology. A goal of this approach is to expose students to foundational concepts in critical ECE areas including wireless communications, micro/nano-technology, computer chips, biotechnology, robotics, power, signal processing, and photonics earlier in the ECE curriculum. The curriculum innovation captures the primary focus of assisting students in understanding and realizing the broader scope of ECE. The laboratory component of the course emphasizes the creation of a context that integrates the societal and environmental impact of the concepts.

This quasi-experimental design involves two groups: participants in the sophomore curriculum innovation course and students that have not taken the sophomore curriculum innovation course. There have been three cohorts of students that have matriculated through this innovative ECE sophomore level course. The study seeks to measure the level of conceptual understanding of key concepts through concept inventories in each of the pillar areas by both groups. The learning experiences of students are also captured in focus groups and interviews.

Introduction

The introductory electrical circuits course at Purdue University and most major research schools in the United States has been taught as a traditional lecture for decades. In these years, the content for the course has stayed relatively constant, with students exploring a handful of topics in great depth. Students begin with elementary concepts such as Ohm's Law, work through topics like nodal and loop analysis, and eventually are asked to analyze RLC circuits. This method is similar to many universities throughout the United States. While this approach tends to provide the brightest students with a wealth of knowledge and skills, other students indicated a great deal of trouble grasping the concepts of circuit analysis. This feedback, combined with a desire to revitalize the electrical engineering curriculum, led to the development of a new introductory circuits course that highlights a broader range of topics while maintaining sufficient depth.

Background and Motivation

The School of Electrical and Computer Engineering at Purdue University has faced some challenges in retaining students beyond the introductory circuits course. The course has a relatively high fail rate, and according to student interviews, is a major barrier to continuing in

Electrical and Computer Engineering. These factors led to an exploration of why students stay in ECE, why they leave, and what about the introductory circuits course is a deterrent.

Based on observations from these studies, a new course was developed by the School of Electrical and Computer Engineering and Prof. Peroulis. Prof. Peroulis also developed the necessary material (videos, notes, etc.) for teaching this course following a flipped classroom approach. The goal of this course was to entirely revamp the sophomore curriculum for Electrical and Computer Engineering. Students indicated a lack of understanding of the discipline of ECE. This failure to see the big picture of the discipline hinted at the need for a broader introductory course with a stronger emphasis on different fields inside of ECE rather than a deep exploration of circuit theory.

The observation that students in the early stages of their careers do not have a strong grasp of what Electrical and Computer engineers do is reflected in the literature.(Graaf, Wright, Walker, & Welch, n.d.; Sturm & Wolfe, 1996). An understanding of the discipline has also been linked to increased retention and enthusiasm. This led to the development of a course that, rather than focus solely on circuit theory, addresses three main topic areas in Electrical Engineering:

1. Electromagnetics
2. Circuits
3. Solid-State Devices

The changes discussed here are illustrated in Figures 1 and 2.

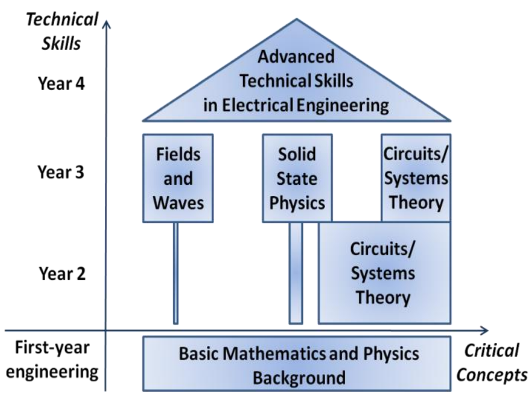

Figure 1 - Traditional curriculum

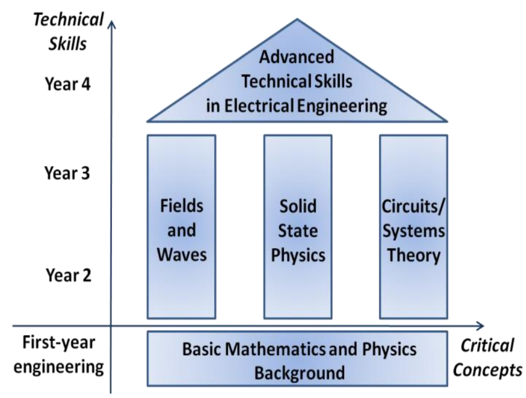

Figure 2 - New curriculum

The new course, ECE201H, was initially offered as an honors-only course for its first two semesters. This provided a chance to identify potential stumbling blocks without negatively impacting an entire class of students. The lessons learned in teaching this version of the course will be applied so that the course is suitable for all electrical engineering students.

Of course, changes to an introductory course necessitate modifications to the other courses in the curriculum if the same material is still to be covered. While this paper focuses primarily on the introductory circuits course, the overall goal of this project is to transform the entire Electrical Engineering curriculum to more accurately reflect what a modern electrical engineer should know. As the focus of Electrical and Computer Engineering shifts away from purely analog circuit design, the content taught at the introductory level should as well.

The first phase of this shift has continued with the introduction of a second circuits course that builds on the experimental course discussed here. Other upper-level courses, such as those dealing with semiconductor circuits, electric field theory, and solid-state devices will need to similarly be modified. In the mean time, however, the content covered in the experimental course should be sufficient to transition students into the current curriculum without much difficulty.

Course Description

The following objectives were developed for ECE201H:

1. An ability to determine the electrostatic potential or electric field, given a simple electric charge distribution or an assembly of charged conductors.
2. An ability to solve for the magnetic flux density for simple magnetic systems, driven by either electric currents or permanent magnets.
3. An ability to define and explain the meaning/function of charge, current, voltage, power, energy, R, L, C, and the fundamental principles of Ohm's law, KVL and KCL.
4. An ability to write the equilibrium equations for a given network and solve using appropriate methods as needed for the steady state (dc and ac/phasor) solution.
5. An ability to state and apply the principles of superposition, linearity, source transformations, and Thevenin/Norton equivalent circuits to simplify the analysis of circuits and/or the computation of responses.
6. An ability to qualitatively predict and compute the step responses of first order (RL and RC) and circuits.
7. An ability to solve for the electromotive force and the displacement current.
8. An ability to understand the operation of the pn junction and the associated built-in potential.

These objectives were chosen to provide students with an overview of three main areas in Electrical Engineering. Approximately five weeks were spent on electromagnetism, while seven weeks were spent on circuit theory. Finally, around three weeks were spent introducing solid-state devices.

As can be seen from the course objectives, students in this course are expected to learn about DC and first-order AC circuits. Traditionally, the introductory circuits course at this university has also covered second-order circuits. Moving this to the second circuits course is the only content that has been removed from the scope of the first course.

It is impossible to discuss the impact of a single course within a curriculum without examining the curriculum as a whole. A typical second-year student in Electrical and Computer Engineering takes one full year of circuit analysis, a semester of electromagnetism through the Physics department, a semester of multivariable calculus, a semester of differential equations or linear algebra, and a semester of semiconductor circuits. Students with a Computer Engineering focus also are likely to take courses in Digital Design and C Programming.

As can be seen from this description, the experimental course presented here touches on many of the areas that are later addressed in the second year. One of the challenges with this course is that it begins with electromagnetism, a topic that can be difficult to understand without the notions of flux and curl. These are introduced in multivariable calculus, a course most students would not have taken when enrolled in their introductory Electrical Engineering course. In order to address this issue, the electromagnetism concepts were presented in a way meant to provide a learning experience that benefitted all students but scaled linearly with preexisting mathematical knowledge. Thus, students who had no experience with multivariable calculus would still be able to grasp concepts, while those who were already well-versed in mathematics could solve complex numerical problems.

Assessment Methodology

Research Questions

By viewing the course through the "How People Learn" framework (D.Bransford, L.Brown, & R.Cocking, 2000), the authors identified four different criteria on which to assess the course:

1. Do students find the new course helps them to better understand the "big picture" of electrical engineering? (Student-centered)
2. Did the teamwork aspects of the course improve their understanding of course material? (Community-centered)
3. Did students feel that the learning activities in the course adequately prepared them for future courses? (Assessment-centered)
4. Did students gain an adequate conceptual understanding of the concepts covered? (Knowledge-centered)

Instruments

Two sets of instruments were used to help answer the questions posed above.

First, an in-class focus group was conducted. Thirty-seven students participated in this session. Participants filled out a written survey that included open-ended questions and Likert scale probings. Discussions were proctored and coded by the authors of this paper who were not part of the teaching staff for the course. The goal of the focus group sessions was to address the student, community, and assessment-centered research questions.

For this initial research effort, students were asked directly whether their views on the field of Electrical Engineering were changed by the course. This is not a perfect measure of how well a course shaped student perceptions, as any changes may not actually have been for the better. However, it is the authors' belief that a change in perception that is fueled by a broader curriculum should more accurately reflect the status of the discipline. To make sure that this is the case, students were asked to explain why they responded the way they did.

A similar method was used to determine how students felt about working in groups. Their views on informal and formal teaming were recorded.

Focus group participants were also asked to rate their confidence in their ability to solve Electrical Engineering problems. This is an indicator of future performance that will be augmented by actual student scores as the research continues. Fostering confidence and conceptual understanding are related but different goals, and both must be assessed.

Two concept inventories were given to students near the end of the course: the Circuits Concept Inventory and Electromagnetics Concept Inventory – Fields (Notaros, 2002). The Circuits Concept Inventory was selected because it combined questions which challenged both conceptual and computational ability. The solid-state component of the course was much shorter than the others, and thus no concept inventory was given for it.

Course participants were almost entirely sophomores in Electrical and Computer Engineering. The course does satisfy a requirement for other engineering majors, and three non-ECE upperclassmen were included in this study. Students' participation in two different honors programs was also tracked. The university offers a first-year engineering honors program as well as a university-wide honors program. These statistics are presented in Table 1. While the enrollment is mixed, there is a significant honors population.

Major	No Honors	First-Year Honors	University Honors	Both Honors
EE	8	5	5	1
CmpE	5	3	4	3

Table 1 - Enrollment of ECE Students

Results and Discussion

The class-wide focus group sought to elicit student opinions on a variety of areas. Most notable for this paper were questions related to the content and format of the course. Numerical results from the questions offered in a Likert scale format are presented here. In the following figures, a 1 represents "Strongly disagree" while 5 represents "Strongly agree". This section also includes a discussion of the themes that came up during verbal discussion.

In order to determine whether students viewed Electrical Engineering differently after taking this course, students were asked if their impression of the field of Electrical Engineering had changed from taking this course and if they were more likely to pursue a degree in Electrical and Computer Engineering because of the course. Their answers to these questions are plotted in Figures 3 and 4.

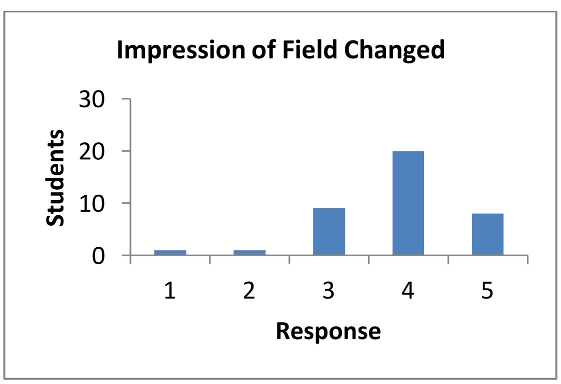

Figure 3 - Focus group question #1

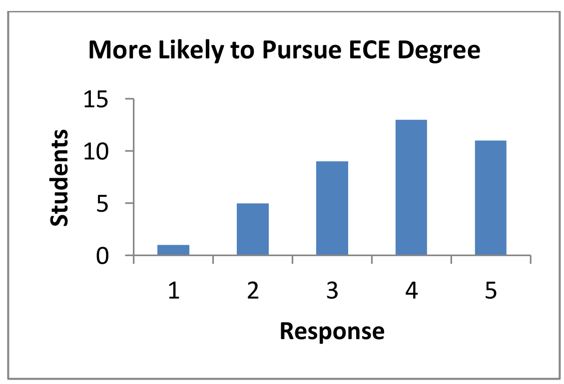

Figure 4 - Focus group question #2

Table 2 presents these results in a slightly different format, tabulating students' responses to the first question in the leftmost column with the response to the second question going across the row.

Response	1	2	3	4	5
1					1
2		1			
3		2	3	3	1
4		1	6	10	3
5	**1**	**1**			6

Table 2 - Likelihood of pursuing ECE degree

The bold numbers in Table 2 (respondents who strongly agreed that their impression of the field changed, but were still very unlikely to pursue an ECE degree) correspond to responses given by students who were already very advanced in a non-ECE major.

Student opinions on the teamwork methods utilized by the course varied greatly. An analysis of verbal responses to questions in this area revealed that many students felt the informal teams often led to one student completing all the work for group exercises, while other students suffered. When asked if they would prefer having formal teams, a majority of respondents seemed to think this would not have helped, as students began sitting together and forming de facto teams anyway.

In evaluating student opinions on course content, students were first asked whether they liked learning about three different content areas. The response distribution is presented in Figure 2. They were also asked their opinion on whether each topic was covered in sufficient depth. These results are given in Figure 3. An initial glance indicates that students did enjoy the course content and feel prepared for future courses. However, they did express some concern over the balance of the three content areas in the course. When asked how they would change the amount of time spent on each component, they were divided. There was an almost-even split between those who wanted to increase the solid-state component and those who wanted to remove it. Students could not come to unanimous agreement on what to do with the amount of time spent on circuits, but there was a strong consensus that wanted to increase this component. Others indicated a desire for less time spent on electromagnetism because this content is covered in a required Physics course.

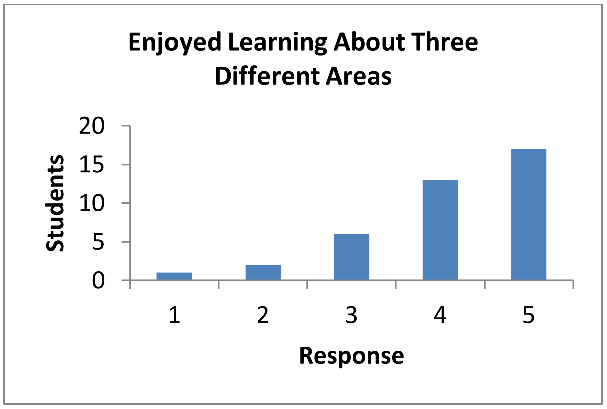

Figure 5 - Focus group question #1

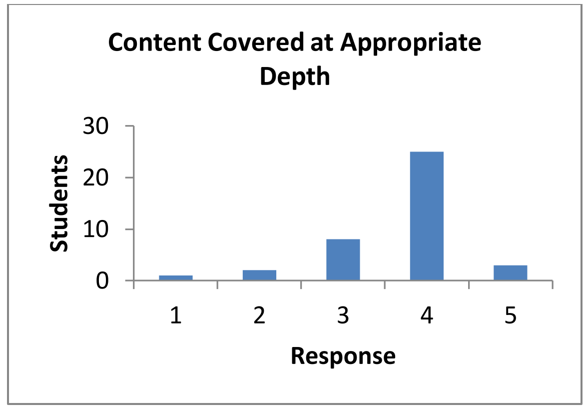

Figure 6 - Focus group question #2

Student performance on two concept inventories was used to gauge conceptual understanding. The performance is included here as a first reference point; however, the results are not as meaningful without a comparison group. In the future, these inventories will either be given before and after taking the course or to students in different courses.

The first concept inventory given was the Circuits Concept Inventory, developed at the University of Massachusetts-Dartmouth. This inventory covers AC and DC circuits and requires computation as well as conceptual understanding. While it would have been ideal to give this inventory to the traditional course as well, time constraints limited this possibility. Even without this data, the scores obtained on the inventory provided a strong indication that, even with less time spent in class, students obtained a strong understanding of basic circuit theory. The average score was 88.85% with a median of 90.48%. This number is presented here to be used as a comparison with future examinations. The same exam will be given to students of the traditional circuits course in the future, though this was not completed in time for inclusion here.

Performance on the second concept inventory, the Electromagnetics Concept Inventory – Fields, was less uniform. This inventory is aimed at students in a first-semester electromagnetic course, so the range of topics covered is broader than what could be introduced in this course. Students achieved an average score of 56.29% on this exam. Like the Circuits Concept Inventory, this number is presented here but will not provide much insight until this exam can be administered to students who have taken traditional electromagnetics courses.

Conclusions

Students had an overall positive view of the course, and many did indicate that their perceptions of Electrical and Computer Engineering were changed. An examination of the cross-tabulated data in Table 2 indicates a correlation between student commitment to ECE and the course's impact on a student's impression of the field. This provides hope for increased retention. An examination of student retention will be performed in the future when enough time has passed to allow for a student to progress through the entire curriculum. In addition, it is important to remember that this course features a higher population of honors students than a typical course, and these results will not necessarily translate to a standard population.

Students did not, in general, feel that the informal teaming methods used in the course fostered any sense of community. The prevalence of students indicating that this method often resulted in only a few students truly doing any work poses a challenge for future offerings of the course. While the authors believe that an ability to work on teams is essential for students to be successful in later courses as well as in industry, it does not seem that the specific methods used here were well-received by students. Results from an instrument evaluating teaming skills would be a useful complement to student opinions and will likely be included as the changes presented here continue to be evaluated.

Increasing breadth proved to be a popular component of the course, and this is the critical component of the curricular changes proposed here. Not only was the increase in breadth popular, student performance on a standardized concept inventory indicated that students gleaned the appropriate conceptual knowledge on circuits from the course. A more in-depth look at performance on the EMCI is required and will be presented in the final version of this paper.

Future Work

This work has explored a small sample size of students who participated in an experimental course. Future work will focus on expanding this sample size to a larger set of students. In addition, the course will be renamed to remove any implication that it is for honors students. This should allow for a broader range of students participating in the experimental course, and possibly a different data set.

The curriculum modifications described above will be carried out in full. Courses will be modified to fit the new curriculum for at least a small cohort of students. The effects of these changes will be examined in a fashion similar to that utilized in this paper. Industry representatives will be consulted throughout the process to ensure that the planned changes are consistent with what students will be expected to know upon commencing their careers.

Future research questions will include generalizing the results obtained here to other areas of Electrical and Computer Engineering, as well as other engineering disciplines. Does providing a broader experience early in a student's career lead to increased learning, interest, and retention? If so, how can we develop these broad curricula while maintaining the depth that is expected of engineering graduates?

More research questions will also arise when the community aspect of these courses is considered. What is the appropriate mix of inverted learning courses and traditional lecture? Does informal teaming provide the same well-known benefits that are seen in courses with well-defined formal teams? How do students respond to teaming challenges when they know they will only be working together for a short time period?

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