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Student Progress after a Learning in Advance Course to Prepare Engineering Students for Circuit Analysis in Electrical Engineering

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Introduction

The University of Alabama (UA) is exploring Learning in Advance (LIA) courses to introduce engineering students to core course concepts prior to encountering them in subsequent "gateway" courses [1]. The term gateway is applied to those courses identified as critical to success in that specific engineering discipline. At UA the gateway courses in electrical/computer engineering, mechanical/aerospace engineering, and computer science are electric circuits (ECE 225), statics (AEM 201), and data structures/algorithms (CS 201), respectively. On a review of institutional data from 2010 to 2015, the rate of students earning grades of D, F, or withdrawing from the course (referred to as the DFW rate) for these gateway courses was: 15-20% for electrical circuits, 25-35% for statics, and 45-50% for data structures/algorithms. To reduce the DFW rate in these courses, the LIA courses were designed to cover approximately 35% of the concept's students will encounter in the associated gateway course focusing on mastery of these concepts at a high level. Preparing students for a specific course is a strong component of many summer bridge programs, thus placing the strategy among evidence-based approaches for improving retention in STEM fields [1-4] and providing justification for exploration in this project.

Focusing on the gateway course for electrical and computer engineering students, ECE 225 is students first introduction to circuit analysis and is expected to be taken during their sophomore year. Successful completion of this course is required for students to progress through their degree, as ECE 225 is a pre-requisite for 4 program requirements that students are expected to take during their junior year. Students who receive a D, F, or W in ECE 225 face significant delays in making progress towards completing their undergraduate degrees. This motivates continued efforts to explore and evaluate interventions (such as the LIA course) that increase student success in this course. In this work, an overview of the electric circuits LIA prep course is provided with an analysis of student performance in both prep and gateway courses to identify if this effort is successful in its aim (to reduce the DFW rate of students in ECE 225). Student feedback from institutional surveys of the students registered in the course is also provided to provide further insight into their experience. Finally, lessons learned from the development and delivery of the prep course are provided to help inform faculty interested in offering similar style courses at their own institution.

Circuits Prep Course Overview

The circuits prep course (ENGR 191-002) is a one-credit, graded course delivered for the first 8-weeks of the 15-week semester. To enroll students are required to complete an online application for review by the course instructor. This application asks for students' performance in their previous math and physics courses and the semester they expect to enroll in ECE 225. Students on track to take ECE 225 in the semester following their application and enrolled in the pre-requisite physics and math courses for ECE 225 are accepted for the course. Those students who do not have the necessary pre-requisites are encouraged to apply for the course in future semesters.

For the 8-week of the course students attend two 75-minute, in-person lectures per week. As a short course with focused instructor interaction in small class sizes, attendance is mandatory. Students who have 2 or more unexcused absences are recommended to withdraw and apply again for enrollment in future semesters.

To prepare students for ECE 225, the prep course covers: basic electrical units, Ohms Law, passive sign convention, Kirchhoff's laws, resistor equivalence, current/voltage division, node-voltage and mesh-current analysis techniques, source transformations, Thevenin/Norton equivalence, and superposition. Each topic is generally covered in one lecture, though node-voltage, mesh-current, and Thevenin/Norton equivalence are covered in two lectures due to their increased complexity. In the most recent iterations, each student is provided a workbook that contains most of the course notes but with sections and examples missing. A sample of a blank and completed circuits example is given in Fig. 1 to illustrate this workbook. In lecture, the theory and notes are discussed with an opportunity for students to fill in the missing sections and complete the in-class examples (often as part of think-pair-share activities). Previous reports on the use of workbooks in engineering courses is positive [6, 7] with Washuta et. al noting student perception of workbooks in their mechanical engineering courses was positive with students favoring important lesson materials in a concise format and saving them time searching through the textbook for important course details [7]. The concise and focused style of the workbook fits the goals and structure of the prep-course very well and provides students an additional supplement of material for when they do take the gateway course.

To evaluate students understanding and mastery of the course material, each student completes 13 online quizzes (one after each lecture) and 3 examinations. The online quizzes are short, timed (15 minutes) assessments with 2-3 multiple choice questions that are due the day following the lecture. Their intent is to support consistent engagement with the course material. Prior to completing the quizzes, students are encouraged to complete a series of practice problems that are available based on the lecture content for that day. These practice problems have completed written solutions and asynchronous video demonstrations available to support students during their solving of them.

The lecture examples and online quizzes aim to prepare students for 3 in-class examinations during the course which test students on their mastery of the course material. For the in-class examinations, students are allowed to bring in a one-page "support" sheet with formulas, examples, and other notes to support their solving of the exam questions. To encourage mastery, students are given one re-take attempt after each exam. During this re-take they are given the opportunity to solve additional problems focused on the topics they did show mastery of on the original exam. At the end of the course, final grades are calculated with 25% weighted to the quizzes (after dropping the lowest two scores) and 25% to each of the course examinations.

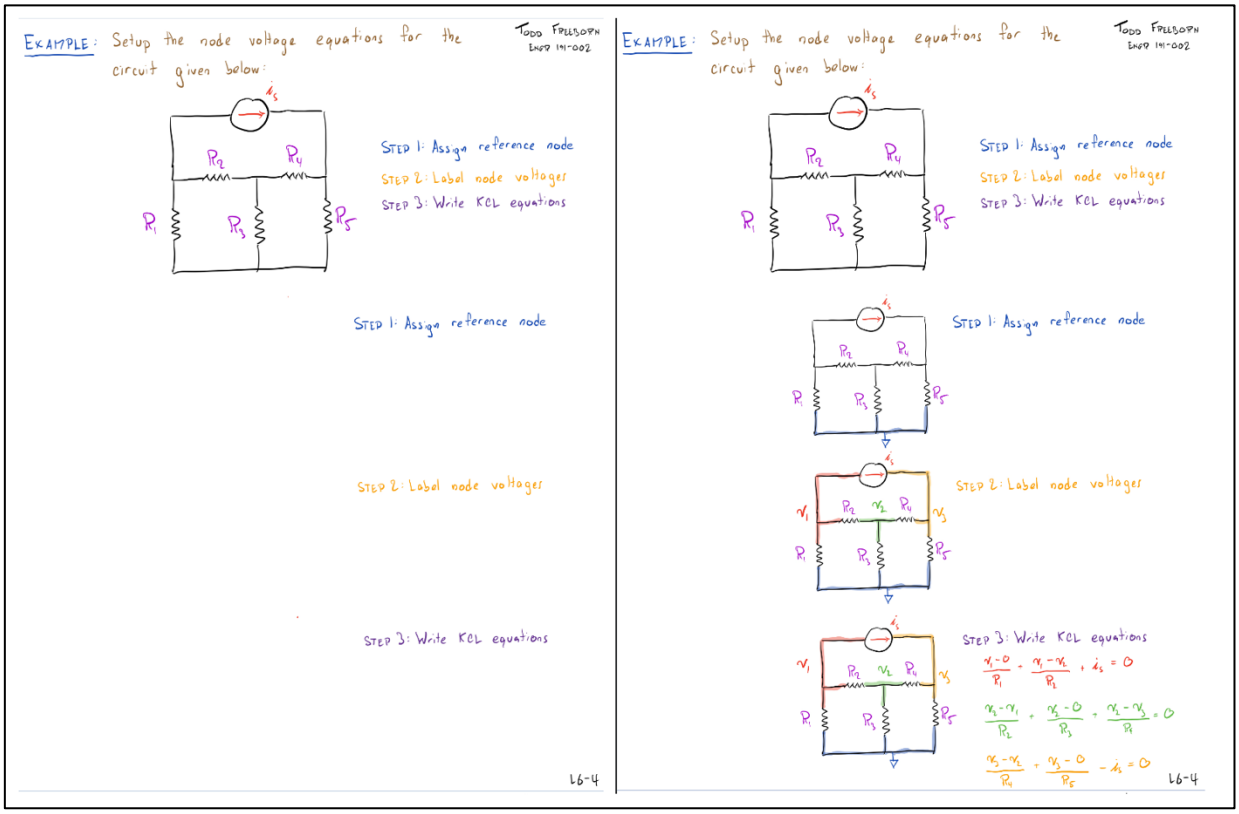

Figure 1: Sample of "empty" and "completed" page from notes-package provided to students in ENGR 191-002 (Circuits Prep).

Summary of Student Performance

To date, the LIA course for electrical circuits prep (ENGR 191-002) has been delivered during the fall and spring semesters from 2017 to 2021. Across this period, 78 students have completed the prep course with 53 of those students having completed the gateway course. A summary of the performance of these students in both prep and gateway courses is given in Table 1. This details the average prep course grade, average gateway course grade, and the average number of semesters between taking the prep and gateway course.

The average grades in Table 1 for both prep and gateway courses represent the values after converting students final letter grade to a representative numeric value (e.g. A+ to 4.3, A to 4.0, A- to 3.7, B+ to 3.3, etc.).

Table 1: Summary of student performance in circuits prep (ENGR 191-002) and gateway course (ECE 225) from the Fall 2017 to Fall 2021 semesters.

	Semester									Total
	F17	**S18**	**F18**	**S19**	**F19**	**S20**	**F20**	**S21**	**F21**	
Circuits prep students	7	5	9	8	12	10	9	5	13	**78**
Students successful in gateway	6	4	8	7	12	8	4	4	0	**53**
Students unsuccessful at gateway (DFW)	0	0	1	0	0	0	1	1	0	**3**
Average prep grade	P	4.18 (A+)	3.84 (A-)	3.9 (A)	3.92 (A)	3.9 (A)	3.63 (A-)	3.8 (A)	3.62 (A-)	**3.82 (A-)**
Average gateway grade	2.95 (B)	3.08 (B)	2.49 (C+)	2.99 (B)	3.46 (B+)	2.91 (B)	2.65 (B-)	2.75 (B-)	N/A	**2.90 (B)**
Average semesters between prep and gateway	2.5	1.75	3.25	3.71	1.58	2.25	1.00	2.00	N/A	**1.62**

For these conversions the semester of Spring 2020 provides a unique case. During this semester, classes at UA (and across the world) were transitioned to virtual delivery mid-semester due to the COVID-19 global pandemic. As a result, an institutional policy was enacted at UA providing students the option to opt for their courses to be recorded as pass/fail or as the standard letter grade. A total of 10 students who completed the prep course were in the gateway course during the Fall 2020 semester, with 8 using the pass/fail option (all of whom earned a pass). These 8 grades were not used in the calculations given in Table 1 since the grade of P cannot differentiate student performance; it was assigned for all students deemed to earn a minimum satisfactory score (that is, greater than or equal to D-). There were no grades of P assigned to the prep course in Spring 2020 as all students opted to use the standard letter grade.

Another note regarding the values in Table 1 is that the average grade for Fall 2017 is represented as P (Pass). Fall 2017 was the pilot trial which graded students on a pass/fail basis and not a letter grade. All 7 participating students in the trial earned a passing grade based on their performance.

Overall, the average performance of students in the prep course is high, with an average of 3.82 (slightly higher than an A- average) across all iterations of the course. This supports those students were showing mastery of the prep course material on their quizzes and course examinations. While the average performance of students in the gateway course was a letter grade lower than the prep (2.90 compared to 3.82) this average (slightly lower than a B) still supports those students were performing at an above-average manner. Of note is only 3 students who have taken both the prep and gateway courses earned a grade of D, F, or W in the gateway course. This represents a DFW rate of 5.6% compared to the 15-20% for the population of students taking the gateway course from the institutional records collected in 2015. For further

comparison, the DFW rate for the 454 students in ECE 225 from Spring 2018 to Fall 2020 was 34.1%. This highlights that the students who have completed the prep course ahead of the gateway have a significantly lower DFW rate than the general population of students taking ECE 225.

Comparison of Student Performance in Gateway to Post-Prep Time

While students are not required to enroll in the gateway course immediately following their completion of the prep course, it is recommended. It is expected that students will take most advantage of the skills developed in the prep course if they are able to utilize them without a significant gap in time. In practice, most students are expected to take the prep course 1 or 2 semesters prior to the gateway course; 1 semester prior for students in fall iterations of the prep class and 2 semesters prior for students in the spring iterations (interrupted by the summer semester during which most students do not take courses). The average number of semesters between prep and gateway courses for students that have completed both is 1.62 (ranging from 1 to 3.71 for all semesters in Table 1).

To explore the relationship between student performance in the gateway performance in relation to the time since the prep course, a scatterplot with these paired details is given in Fig. 2. Each dot in this scatterplot represents a gateway course final grade / number of semesters between prep & gateway data pair. The color of each point on the scatterplot represents how many datapoints overlay that point; dark blue representing 1 student and yellow representing 13. For

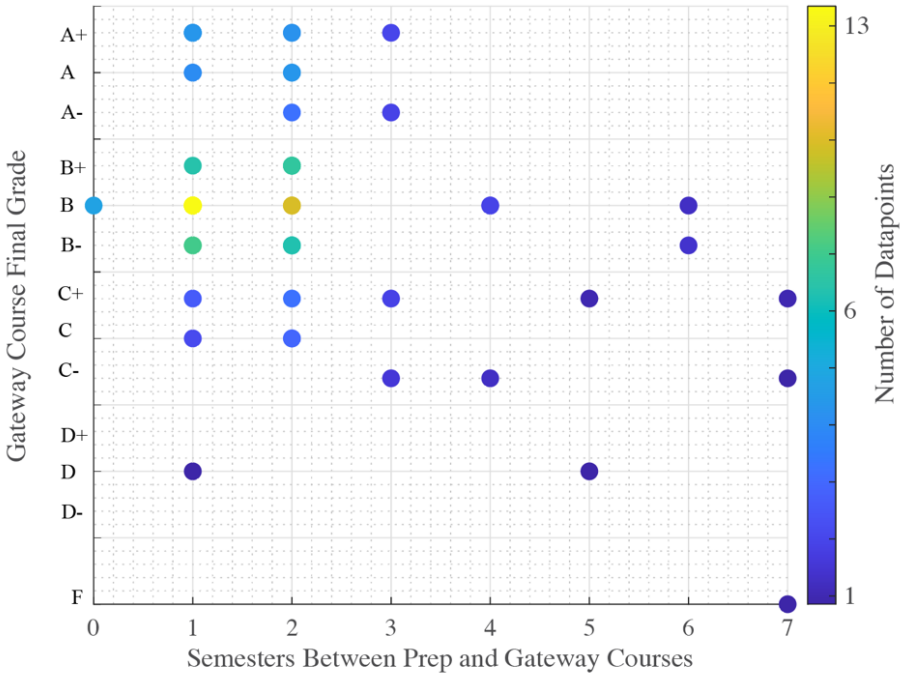

Figure 2: Scatterplot representing paired student data of gateway course final grade with the number of semesters between prep and gateway courses. The color of each dot represents the number of student datapionts at this location.

this figure, students with a grade of P were given a numeric value of 3 to represent the average grade of this grouping.

From the Fig. 2 scatterplot, notice that a higher proportion of students obtain grades of B- in the gateway course when it is completed within 3 semesters of completing the prep course. It is interesting to note that no student who completed the gateway course 4 or more semesters after the prep course earned a grade higher than B. However, it is important to note that this observation does not elucidate the source of lower performance for these students. One hypothesis for this lower performance is the atrophy of skills developed in the prep class with a long delay before their application in the prep course. Alternatively, the delays could be a result of students failing to successfully complete the pre-requisite courses to take ECE 225. The prep course is usually taken concurrently with a general physics course and a calculus course, both of which are pre-requisites for electrical circuits. Failure to complete either course prevents taking the circuits gateway course (even if the prep course is completed successfully) and delays student progress towards degree completion resulting from having to repeat. However, further research is needed to investigate the source of these delays and evaluate strategies to reduce the delay and increase student success.

Student Opinions of Instruction on Prep Course

At the end of each semester, the University of Alabama solicits student opinions of instruction (SOI) from students enrolled in their courses. These surveys ask students to provide numeric ratings (from 1 to 5, with 1 being the most negative and 5 being the most positive) regarding their courses and instructors. The average ratings from the SOI scores (provided by the course instructor) for the prompts: **1)** The course was a valuable learning experience (*Experience*) and **2)** How would you rate this course? (*Course Rating)* are provided in Table 2 for the Fall 2018 to Fall 2021 iterations of the prep course. A total of 49 students provided ratings which is a response rate of 72.4%.

Table 2: Summary of student options of instruction related to the circuits prep (ENGR 191-002) course from Fall 2018 to Fall 2021 semesters.

	Semester							Total
	F18	**S19**	**F19**	**S20**	**F20**	**S21**	**F21**	
Circuits prep students	9	8	12	10	9	5	13	**66**
SOI responses	7	6	11	6	7	4	8	**49**
Experience	5.00	5.00	4.91	5.00	5.00	5.00	4.88	**4.96**
Course Rating	4.86	5.00	4.91	5.00	5.00	5.00	4.88	**4.94**

The feedback for both questions is extremely positive with ratings >4.8 for all iterations contributing to weighted averages of 4.96 and 4.94 (out of 5) for the student opinions on the value of the learning experience and rating of the course, respectively. In addition to the numerical ratings, the SOI survey prompts the students to provide written feedback regarding both the instructor and the course. Samples of the feedback provided by the students regarding the course is given below to provide further insight into their experiences:

- "I appreciated the structure of the course and how organized everything was."
- "While this is obviously a smaller class because it is a prep course, I felt like I was able to hammer out any questions or missteps that I had with the material and problems sets and [the instructor] helped explain these things [in] a way that would be hard to do in a larger lecture style class, especially when it might feel like you are the only one in a class of 100 people that doesn't understand something"
- "This course will benefit me in ECE 225. The grading was very lenient since we had two attempts on each exam. There was clearly an emphasis on making sure we mastered the material, even if we failed a test. My only complaint was that the practice problems and notes were taken from a different course, so the problems were sometimes worked out differently than taught in class."
- "This course went about as how I would expect a preparatory class to go. It didn't ask much more of you than to keep up with the current topic of material. I really liked the in-class examples that were much more complicated and expansive than the quiz and test material, as these both gave you a taste of what to come and fully prepared you for any type of question to be asked on an assessment."
- "It would be very good to go over more material and extend the length of the course for more preparation"
- "I loved the constant testing of materials (quizzes), but I think written quizzes or homework assignments might be more beneficial. In having the work written out and graded, students would be able to look back over their thought processes and see exactly where they went wrong. With the online quizzes, I was tempted to try and do the problems in my head or write out minimal work. Due to this I wasn't really sure how I made mistakes or where I messed up- I just knew I got the answer wrong."
- "Biggest highlight is that the prep course is very well-structured: A topic a day, you get the lecture and in class practice, and a quiz to reinforce what you've learned. I'm also extremely grateful there weren't homework to be stressed about. And the fact that you're allowed to retake exams to encourage mastering the material, well damn that's what education should always be. Can't really complain, honestly. The worst thing I can say about the class, is that I wished it covered even more material on capacitance and inductance to further prep us for ECE 225, given how hard/gatekeeping that class sounds."
- "I seriously hope there are more chances to take precourses like this one for difficult classes. I feel like I learned so much in a short period because the schedule was very effectively set up."

The students written responses provide further insight into the aspects of the course that are contributing to their high SOI ratings. Specifically, students report that the course structure (lectures, quizzes, exams) supported their learning and experience, the focus on mastery with the ability to re-take exams was well regarded, and the focused time with the course instructor in a small class supported their individual progress. The feedback that students would be interested in covering additional material and pursuing prep courses for other topics also supports that they found these experiences beneficial.

Lessons Learned

Across the 9 iterations of prep course delivery from 2017 to 2021, the following lessons (and their subsequent program revisions) were made that may be of interest to instructors aiming to develop their own learning-in-advance courses:

- From Fall 2017 to Spring 2019, course quizzes were given at the start of each lecture with students having 10 minutes of in-class time to complete. However, this reduced the amount of course time to cover content. Therefore, to increase time dedicated for in-class activities the quizzes were transitioned online and to be completed after each class in the course learning management system (Blackboard). While this increased course development effort in the Fall 2019 semester, it has reduced instructor grading in all subsequent semesters with no negative comments regarding the format or out of class workload by students in the course. This approach is recommended for similar style courses to facilitate increased interaction time between students and instructor during the short, focused course.

- The facilitation of re-take attempts on course examinations is a well-regarded component of the prep course that supports student mastery of course material. However, it is necessary to clearly structure the re-take opportunities to encourage students to increase the quality and quantity of their studying prior to a re-take. Early iterations of the course allowed multiple exam retakes, but it was noted that students often did not study between their attempts which limited their mastery of the material and increased the instructor workload to redesign new test questions. In the current course iteration, students are allowed 1 re-take opportunity which must be completed within 1-week of receiving the feedback on their first attempt AND provide an analysis of what they did wrong on their first attempt with proof of completing 1-2 practice problems to master that topic. This encourages students to identify their problem areas and focus their additional studying on those topics all within a quick time-frame so that these efforts help them with further topics in the course. This is highly recommended for programs interested in integrating re-take opportunities into their courses.

- The initial workbooks used in the prep course were re-purposed from a different electrical circuits course at UA. This course, ECE 320 (Introduction to Electrical Circuits and Systems), is the electrical circuits course for non-electrical students but covers similar material to ECE 225 (gateway course for ECE students). While the content of the workbook was the same as ECE 225, the structure of when material was covered was different than the prep course format. As a result, students were often required to move between sections and not complete them sequentially. Both the alteration in structure and references to a different course name (ECE 320) appeared to impact students' perceptions of the workbook (e.g. "My only complaint was that the practice problems and notes were taken from a different course"). To resolve, the workbook was revised to align with the course naming and structure of the prep class. After this revision no further student feedback regarding a disconnect between the workbook or structure was reported.

Limitations

It is important to consider the limitations of our analysis of the LIA approach to preparing ECE students for electrical circuits. While this analysis supports those students who have completed the prep course have a lower DFW rate in the gateway course than the general population of ECE students who take it, further analysis is needed to confirm that it is the intervention (e.g. the prep course) that is responsible for this change (and not just the select population of students).

It is important to consider that the prep course is not a program requirement and enrolled students are generally taking this course in addition to their regular program requirements. As a result, students already struggling with their current course loads may not be applying to the program (even though it is this population that is expected to benefit the most from the prep course). This may result in a high proportion of already high-achieving students, who are comfortable with the overload and seeking opportunities to further increase their success, taking the prep class. To evaluate this, further research that explores the relationship between student performance in the electrical circuits' pre-requisites and the gateway course in populations that have and have not taken the prep course is necessary.

Conclusion

The Learning in Advance prep course focused on introducing electrical and computer engineering students to circuits analysis concepts prior to the gateway course in electric circuits has been a success both in terms of student performance in the gateway course and reported students' experience. Students who have completed the prep course have a lower DFW rate (5.6%) in the gateway course compared to recent rates of all students in the gateway course (34.1%) and report high levels of satisfaction (4.8 out of 5) with the course and experience.

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