AC 2011-471: GETTING TO CARNEGIE HALL: NOVEL TIMED HOMEWORK PRACTICE TO DEVELOP BASIC CIRCUIT ANALYSIS SKILLS

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Abstract

Undergraduate education in electrical engineering can be improved by drawing on research on human learning and cognition. One main result of this research is that frequent practice and self-testing are effective and efficient strategies for mastering new information.[1,2] Furthermore, frequent practice promotes speed as well as accuracy. This point is particularly relevant in the field of electrical engineering, as students must master core concepts (e.g., Ohm's law) such that they can apply them quickly and effortlessly in order to efficiently solve more advanced problems. The present project pilot-tested a novel technique for encouraging frequent, fast-paced practice among students in the first circuits course. Nineteen undergraduate engineering majors (including civil, mechanical, environmental and electrical) participated in a face-to-face course in which traditional course activities (lectures, in-class discussion, exams) were supplemented by three online homework modules. These modules differed from traditional homework assignments in the following ways: First, rather than recapping material presented in class, each module focused exclusively on a single *core concept* (Ohm's law, op-amps, or complex numbers). Second, the modules were *repeatable*, such that students were encouraged to submit multiple attempts, with slightly different problems on each attempt. Third, the modules were *timed*, such that students received bonus points tied to how quickly they completed their best attempt. Effectiveness of the online homework modules was assessed by comparing exam scores across the enhanced and traditionally taught versions of the course, and by conducting an end-of-semester opinion survey. Results showed a statistically significant increase in in-class exam scores for the enhanced course compared to the traditional course. Average percent correct on the first exam was 85.7% in the enhanced course, compared to 79.7% in the traditional course, and for the second exam was 81.4% compared to 62.3% in the traditional course. Performance on the third exam was within the acceptable range (74.7%) for the enhanced course, but differences in the exam format (in-class vs. take-home), combined with the large proportion of students not completing the third online homework module, prevented meaningful statistical comparisons. Final exam scores were also statistically compared and showed no differences across the traditional (71.1%) and enhanced (70.9%) sections. Student opinion of the online homework modules was positive, with large majorities responding either "Strongly agree" or "Agree somewhat" to the statements that the modules helped them understand class material, helped them practice skills needed on exams, and were generally useful to the class. Subsidiary analyses focused on predictors of exam performance including number of attempts, best score, best time, and level of academic preparation. Qualitative comments from the instructor and from students were also summarized, with an overall trend toward positive impressions of the online homework modules. Results suggest that repeatable, timed modules focusing on core concepts are an effective way to raise student performance and learning.

Introduction

This project addresses the first linear circuits class at our university, which is taken by majors in electrical, mechanical, civil, and environmental engineering. This introductory course covers basic topics in linear circuits such as Ohm's Law, nodal analysis, Kirchhoff's Laws, op amps, ac analysis, 3-phase power, and transformers. A laboratory component is also required for electrical and mechanical engineering majors. Students typically have a mix of interest in the course material, making this a difficult course to effectively teach all students.

This class has a historically high number of grades of D, F, or W (withdrawal). As a result, we have tried numerous methods to improve the quality of instruction including a course redesign in 2007 and supplemental instruction (an ongoing effort; see http://www.umkc.edu/cad/si/). The latest effort draws on the principles of cognitive psychology to develop timed homework modules on three basic principles of the course. The modules are online and graded automatically. The objective is to give students repeated practice with rapid feedback so that the relevant skills become automatic and can be more easily applied as the student learns additional concepts.

We recognize that most instructors of this class have achieved such a high level of expertise in circuit analysis that it is difficult for them to realize how confusing some of these basic concepts are to novice learners. Experts also tend to forget how much practice is really needed to improve one's level of performance. The basic goal of these modules is to address the most basic fundamental concepts in electric circuits with simple, focused exercises that give novice learners the repeated practice with feedback[1] that helps them develop their circuit analysis skills.

This paper is organized as follows. The Method section details the homework modules, student characteristics and the student opinion survey, while the Results section describes quantitative and qualitative outcomes. Last is the Summary and Conclusion section.

Method

Online Homework Modules. There are many concepts that students must learn in electric circuits. For this pilot study, we chose Ohm's Law, op amps, and phasors as the three basic principles to address in the online homework modules. Ohm's Law is fundamental to everything that is covered in the class. To succeed in the remainder of the course, it is critical that students understand this concept well, and can apply it quickly and accurately. Examples of questions from the Ohm's Law module are shown in Figure 1. The questions included various configurations of current flowing into or out of the positive or negative voltage terminals. Units were required for all of these questions. Students were asked to calculate either the resistance (R), the current (I), or the voltage (V), given the other two. An example question is as follows:

> If the resistor has a resistance of 6.0 Ohm and the current through the resistor is 3.5 A, what is the voltage across the resistor, as shown in the figure?

The values were randomly generated for each student and each attempt. The questions progressed from easier to more difficult and were in a random order within each group of questions. This was done so that each attempt was quite different than previous attempts and students truly needed to read each question to get the correct answer.

The questions are designed to address typical difficulties with Ohm's Law: the correct application of Ohm's Law ($V = IR$), the correct sign for voltage and current, and the correct units. These questions were particularly useful for helping students understand the correct sign for voltage and current.

Op amps are a difficult concept and one that is likely to be useful to students of all majors later, either in class projects or in their professional careers. We followed a similar strategy as with the Ohm's Law module. An example question shown Figure 2, is as follows:

> For the ideal op amp model with $v_s = 3$ V, $R_s = 15$ kOhm, and $R_f = 52$ kOhm, what is i_p in the figure?

Note the answer is 0 mA, regardless of the values of the voltage and resistors. The assessment tool in Vista requires that all variables be used in the calculation of the answer so we used the formula [vs]-[vs]+[rs]-[rs]+[rf]-[rf], where [vs] is the value for v_s, [rs] is the value for R_s, and [rf] is the value for R_f.

Other types of questions included matching of the op amp symbol terminals to the terminal name, calculating the ideal model input voltage and currents, and calculating voltages and currents in a given op amp configuration. These questions were designed to emphasize basic familiarity with the op amp symbol, the ideal model (zero input current and zero voltage drop between the input terminals) as the starting point to analyze any op amp circuit, and the analysis of op amp circuits.

The topic of the third online module was phasors, which includes complex numbers and the conversion between time and frequency domains. These questions required converting complex numbers between rectangular and polar representations, identifying the leading or lagging signal in a phasor diagram or a time-domain waveform, and identifying the magnitude, phase, or frequency of a sinusoidal waveform. See Figure 3 for examples.

For all three modules, students were permitted to attempt each module as many times as they liked. Each module had two scores, the accuracy score and the time score.

Each module consisted of 30 questions, each worth 3 points, for a total of 90 points for the accuracy score. Some questions required a numerical answer. If units were included, the unit answer was 0.6 points and the numerical answer was 2.4 points. Some questions were multiple choice and some were matching.

The time to complete the module was also recorded. If the time used by the student was below a pre-determined limit, the time score was 10 points. For each minute over the limit, the time score was reduced by 1 point. This was to encourage students to work quickly and accurately.

Since the online modules are automatically graded in a learning management system, our approach scales easily with more students. The modules can also be used "as is" in subsequent semesters because the random values and random selection of questions prevents students from simply copying and sharing answers.

The questions were written with Respondus 4.0 [www.respondus.com] while the images were created with Visio 2003 by Microsoft. The questions were then published to Vista with some additional editing to create the questions with an answer of 0. All files are available from the authors.

Student opinion survey. A 10-question survey was presented to students, also in the Vista system. Survey questions covered demographic and academic background and student opinion of the course enhancements. Three closed-ended questions asked students to indicate on a 5-point Agree-Disagree scale their agreement with the following statements:

The online homework assignments helped me understand material presented in class.

The online homework assignments were a useful part of class.

The online homework assignments helped me practice skills needed to do well on exams.

Two open-ended questions asked students to comment on the online homework and the course overall.

Student and class characteristics. These online homework modules were given in the summer 2010, a 10 week semester. The spring and fall semesters are 15 weeks. No laboratory section was offered. There were three exams during the semester and one online homework was given before each exam. The modules were made available for three to four days in advance of the exam. There was also a cumulative final exam. The comparison or "traditional" course was taught by the same instructor in summer 2009. No online homework modules were included in the traditional course, although the exams covered the identical material.

The enhanced course was comprised of 4 female and 15 male students. Of these, there was 1 freshman, 6 sophomores, 10 juniors, and 2 reporting their class standing as "other." University records were used to access other academic background variables. Average cumulative GPA was 2.89. Among those with ACT math scores on file ($N = 5$), the average was 24.4; among those with SAT math scores ($N = 7$), the average was 615.

Results

Three examples of scores on the Ohm's Law Quiz are shown in Table I. Initially, the scores are rather low and increase rapidly. We assume that the students figure out where they make errors and correct those concepts in later attempts. The time generally decreases with additional attempts. The increasing accuracy score and the decreasing time with additional attempts would indicate that students did tend to gain automaticity with additional practice. On average, students attempted each module an average of 3.47 times.

The effectiveness of the online homework modules was assessed by comparing exam scores across the enhanced and traditionally taught versions of the course, and by conducting an end-of-semester opinion survey. Results showed a statistically significant increase in in-class exam scores for the enhanced course compared to the traditional course (F [1, 33] = 6.969, $p = 0.013$). Average percent correct on the first exam was 85.7% in the enhanced course, compared to 79.7% in the traditional course, and for the second exam was 81.4% compared to 62.3% in the traditional course. Performance on the third exam was within the acceptable range (74.7%) for the enhanced course, but differences in the exam format (in-class vs. take-home), combined with the large proportion of students not completing the third online homework module, prevented meaningful statistical comparisons. Final exam scores were also statistically compared and showed no differences across the traditional (71.1%) and enhanced (70.9%) sections. No significant correlations were found between academic preparation variables (SAT, ACT, GPA) and performance, although the small number of participants may obscure these correlations.

Student opinion of the online homework modules was positive. Substantial majorities of students responded “Agree somewhat” or “Strongly agree” to all three questions. Among students who responded to these questions, the breakdown of responses is shown in Table II.

Qualitative comments from students were positive, particularly regarding their helpfulness in learning basic concepts. Several cited frustration around the required response format, particularly the three significant figure requirement, and one commented that the difficulty level ought to be closer to that of the in-class exams. The course instructor was initially skeptical that such simple questions could be effective but found that the students benefited by clearing up misconceptions. Qualitative comments from the course instructor include “Less perplexed faces, less questions about the plus or minus signs and a much better understanding of the concepts. I wish that I had a few more quizzes to cover some of the other topics in [this class].”

Summary and Conclusions

Results suggest that repeatable, timed modules focusing on core concepts are an effective way to raise student performance and learning, and that they were well received by students. Scores on exams that incorporated these core concepts were significantly higher in the section with these timed modules. One caveat is that we did not find significant differences across the comprehensive final exam, for reasons that are not completely clear. It is possible that the gains associated with mastery of core concepts presented early in the course were “diluted” as more material was added later in the semester. It may also be the case that the exam emphasized advanced material much more than these core concepts; the difficulty level of the exam did appear to exceed that of earlier exams, as suggested by the fact that for 13 of the 19 students in the enhanced section, the final exam was the lowest of all of their exam scores.

Our online modules offer several distinct advantages over traditional homework assignments. First, they are structured in a way that encourages students to maximize time spent practicing basic principles. Students understand that it is to their strategic advantage to attempt the homework modules multiple times, forming an effective incentive to do the effortful practice and self-testing that few students undertake on their own.[3] Furthermore, timed frequent practice takes advantage of the cognitive principle of *automaticity*, by which well-learned processes take less of the individual’s limited cognitive capacity, thus leaving more capacity for other tasks, such as learning new concepts or problem-solving.[4,5] Lastly, our system offers rapid feedback and an optimal level of difficulty (not too easy nor too hard), characteristics which can potentially produce the state of optimal cognitive functioning that psychologists refer to as “flow”.[6]

We are continuing to enhance these modules. We have reworked the questions in the op amp module to make the questions more focused on single steps in the solution process. We are developing additional modules on Kirchhoff’s Voltage and Current Laws for dc circuits and working on plans for modules in ac circuits.

References

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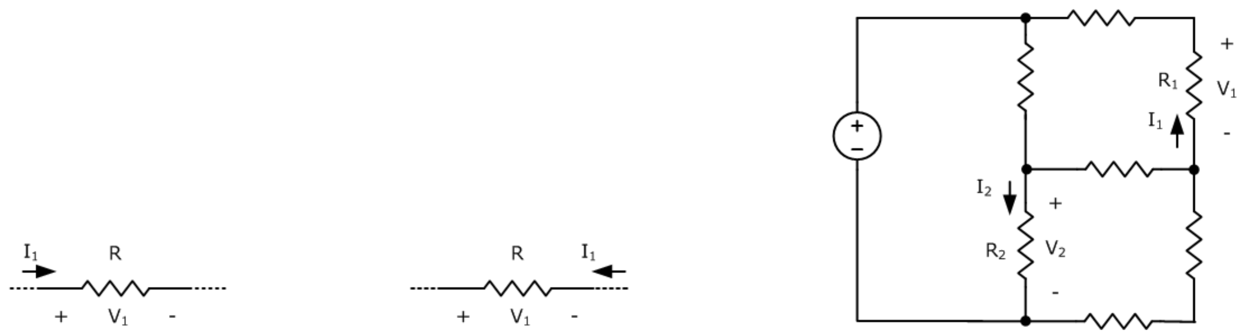


(a) **(b)** **(c)**

Figure 1. Three examples from Ohm's Law questions. Students were asked to calculate either the resistance (R), the current (I), or the voltage (V), given the other two. (a) simple application with positive voltage and current (b) simple application with negative current (or voltage) (c) complex application

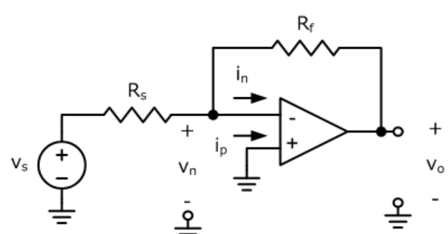
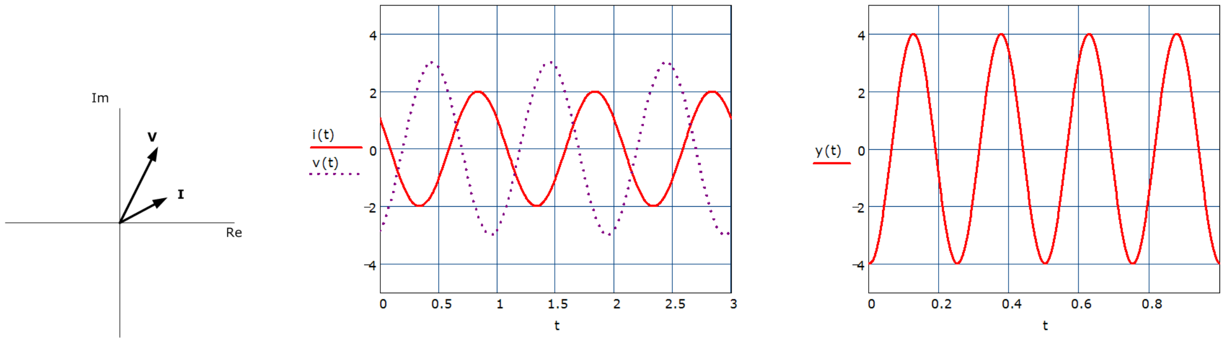


Figure 2. Example from op amp questions.



(a) (b) (c)

Figure 3. Examples from phasors questions. (a) identify leading or lagging V or I (b) identify leading or lagging *i*(*t*) or *v*(*t*) (c) identify magnitude, frequency or phase.

Table I. Three examples of student scores on Ohm's Law module. The module was available until June 11, 1:30 PM.

Student	Attempt and Date	Score	Time
A	1. June 11, 2010 12:50 AM	55.8	00:20:12
	2. June 11, 2010 10:41 AM	66	00:14:01
	3. June 11, 2010 11:05 AM	90	00:10:29
B	1. June 7, 2010 6:43 PM	68.4	00:36:27
	2. June 7, 2010 7:02 PM	75.6	00:12:02
C	1. June 7, 2010 4:46 PM	51.6	00:50:05
	2. June 7, 2010 5:10 PM	87.6	00:14:50

Table II. Student opinion of the online homework modules.

	Strongly agree	Agree somewhat	Neither agree nor disagree	Disagree somewhat	Disagree strongly
Helped me understand material presented in class	5	13	1	0	0
Were a useful part of class	5	12	2	0	0
Helped me practice skills needed to do well on exams	4	12	1	2	0