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Large Lecture Transformation: Improving Student Engagement and Performance through In-class Practice in an Electrical Circuits Course

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ABSTRACT

Post-secondary educators are increasingly experimenting with the possibility of blending or replacing traditional lecture-based instruction with student-centered instruction. Although some studies have been completed, much remains to be learned about when and why student-centered instruction works and the effectiveness of specific approaches. The goal of this study was to investigate the effectiveness of a student-centered instructional approach on students' engagement and achievement in a transformed electrical circuits course compared to the same course taught in a traditional lecture-based format. Two hundred and forty-three students participated in the study. Three surveys were administered during the semester, and participants' demographic information, prior learning outcomes, and course outcomes were collected after the semester was over. The results indicated that students in the student-centered section were significantly more engaged and achieved higher learning outcomes than students in the lecture-based section. The specific instructional strategies and technologies used in the student-centered section are discussed.

Key words: Large classes, circuits, blended instruction

INTRODUCTION

In traditional large lecture courses in engineering, most class time is focused on content delivery, and consequently, most practice occurs outside of class. This paper examines the potential benefits of adopting a student-centered instructional model that uses a web-based feedback system to allow more class time for problem-solving in a large engineering course.

As the theoretical understanding of the process of cognition, learning, and teaching has moved from the behaviorist to constructivist perspective, teaching practices derived from constructivism have gained great popularity in higher education (Savery & Duffy, 1996). The behaviorist view of learning is knowledge acquisition, in which teaching practices are focused on the efficiency of transmitting information, whereas the constructivist view of learning is the active process of construction of understanding, and teaching is focused on coaching to guide students' learning process and understanding their thinking (Greeno, Collins, & Resnick, 1996).

Two sections were taught the same subject in auditoriums. Students in the student-centered section learned the subject through in-class problem-solving activities and homework assignments using a web-based feedback system with the instructor and teaching assistants' guidance, whereas students in the lecture-based section learned the subject through in-class instructor lectures and homework. We compared students' learning outcomes, engagement, self-efficacy, intrinsic values, and test anxiety between the two sections. We hypothesized that students in the student-centered section would achieve better learning outcomes (exam scores) than students in the lecture-based section after controlling for their prior learning outcomes (cumulative grade point average and ACT scores). The course studied was a sophomore-level electrical circuits course offered at a large public university located in the Midwestern United States.

REVIEW OF THE LITERATURE

Student-centered Learning

Teaching practices grounded in the constructivist perspective are commonly referred to as active (Bonwell & Eison, 1991) or student-centered learning. Such learning contexts emphasize inquiry-based learning and problem-solving activities that encourage active participation and interaction during class meetings. Flipped (or, inverted) classrooms are a version of the student-centered approach in which lectures are moved out of the classroom to allow facilitation of the students' learning process through hands-on tasks in class (Gross, Pietri, Anderson, Moyano-Camihort, & Graham, 2015; McCallum, Schultz, Sellke, & Spartz, 2015).

As higher education instructors have adopted student-centered teaching strategies, researchers have begun to examine the effectiveness of student-centered approaches to learning outcomes (e.g., Freeman et al., 2014), and to propose best practices for other instructors. Student-centered approaches often include pedagogies of collaborative/cooperative learning (Johnson & Johnson, 2002), inquiry/problem-based learning (Savery & Duffy, 1996), and frequent formative assessment and informative feedback (Jonassen, 1999) that are focused on students' learning processes rather than distribution of content.

While students' deep cognitive engagement in typical lecture-based classrooms usually occurs when they engage with assigned tasks outside of the classroom, student-centered approaches bring it into the classroom where instructors can observe the learning process and provide timely scaffolds. Because the in-class focus is shifted from content delivery to class activities, such as concept checking, discussions, debates, and various tasks involving application, analysis or problem-solving, student-centered approaches require students to learn course materials prior to a class meeting (McCallum et al., 2015), typically through assigned readings or lecture videos along with quick quizzes or short write-ups. Because students in student-centered courses interact with course materials in a timely manner to prepare better for class meetings, they tend to avoid the cramming style of study for summative assessments compared with students in lecture-based courses (Gross et al., 2015; Hutchings & Quinney, 2015).

Research in student-centered instructional approaches has reported positive outcomes in student learning (e.g., Freeman et al., 2014; Gross et al., 2015; Kim, Patrick, Srivastava, & Law, 2014; Russell et al., 2016; Smith & Cardaciotto, 2011; Tsaushu et al., 2013). Freeman et al. (2014) reported in a meta-analysis study that average examination scores improved by about 6% in the courses that had active learning components, and that students in classes without active learning components were 1.5 times more likely to fail than students in the courses with some form of active learning. Hsiung (2012), in a study of 42 mechanical engineering students, reported that students in the cooperative learning settings performed significantly better than students in the individualistic learning settings. In another study, students in the active learning settings reported greater retention of and engagement with the course material but not greater enjoyment when compared to students in settings focused on content review (Smith & Cardaciotto, 2011).

However, other studies have reported no significant differences in student learning between the two approaches, and have suggested investigating the specific active learning elements in courses (e.g., Velegol, Zappe, & Mahoney, 2015). Students' resistance to new and challenging ways of learning, and cultural resistance manifested in instructor skepticism and the lack of timely and responsive support (Hutchings & Quinney, 2015), have also been acknowledged as affecting the outcomes of student-centered approaches. Hao (2016) reported, in a study of 84 undergraduate education majors, that only 39% of those in flipped classrooms agreed that the flipped classrooms met their learning needs although approximately 60% agreed with the idea of student-centered learning. Moreover, covering the same content material while adding active-learning activities poses an additional challenge to instructors (Kunberger, 2013; Yazedjian & Kolkhorst, 2007).

Engagement and Motivation

Engagement refers to a student's active involvement in a learning activity, and multiple aspects of students' engagement are interrelated such as behavioral, emotional, and cognitive engagement (Reeve, 2012). Behavioral engagement is related to on-task attention and participation, while emotional engagement is associated with task-facilitating emotions such as interest. Cognitive engagement is related to the use of effective learning strategies.

Motivation refers to any force that energizes and directs behavior (Reeve, 2012). It arises or undermines from many different sources. Self-efficacy, intrinsic value, and test anxiety are all motivational constructs that can be strongly associated with learning outcomes (Pintrich & De Groot, 1990). Student engagement and motivation are critical in the academic setting because they are tied to personal and academic success (Black & Deci, 2000; Hagger et al., 2015; Jang, 2008; Jang, Reeve, Ryah, & Kim, 2009; Viorel & Codruta, 2013). Previous research has indicated that student-centered learning is positively associated with classroom engagement and motivation (e.g., Gilboy et al., 2015; Oncu, 2015; Russell et al., 2016).

Web-based Feedback

Web-based feedback systems are often adopted to support students' problem-solving process. They provide immediate feedback, typically in the form of an acknowledgment of the correctness of a response or suggestions for improvement. The effectiveness of these systems on student problem-solving performance has been evaluated in various disciplines (e.g., Crippen & Earl, 2004; Lee, Palazzo, Warnakulassoriya, & Pritchard, 2008). In particular, Lee et al. reported that the hints and feedback of their web-based physics tutoring system helped students acquire concepts more quickly, and importantly, that less skillful students benefited far more from this feedback system than more skillful students. In most cases, these systems were adopted for homework, which students mainly worked outside of class.

COURSE TRANSFORMATION

Course Background

The electrical circuits course investigated in this study is required for all engineering majors. It is typically taken during students' 2nd year after a first course in calculus-based physics and concurrently with a differential equations course. At the university where we conducted our study, three to four sections of this course are offered per year. The typical enrollment of between 140 and 180 students per section. Students attend three 50-minute instructor-led lectures and one 50-minute teaching assistant-led discussion each week. Grades are determined based on a weighted average of students' weekly homework scores, two midterms, and a final examination. The course objectives are to explore fundamental electrical quantities, components, and concepts, and to develop ad hoc and systematic tools for circuit analysis. The learning topics covered are: circuit variables; sources, resistors, and Ohm's law; ad hoc, nodal, and loop analysis; scaling and superposition; the Thévenin-Norton and maximum power theorems; operational amplifiers; capacitors, inductors, and mutual inductance; first-order transient analysis; phasor analysis; and sinusoidal power analysis. The course has no laboratory component but includes several direct-current, transient and alternating-current circuit simulation (Multisim) assignments. The teaching assistants' main role in the course is to lead discussion sessions and to grade weekly homework assignments.

Fundamentally, electrical circuits courses are about problem-solving. Nonetheless, engineering circuits instruction at most institutions has been lecture-based. Concepts and problem-solving strategies are introduced via lectures during class and students are expected to practice and master the concepts and problem strategies outside of class. Therefore, if students make time outside of class to grapple with concepts and solve a variety of problems, they can be successful. Unfortunately, due to time constraints or the lack of timely help, students are asked to solve only homework problems and a few practice problems. As a consequence, many students have a hard time achieving excellence in major course assessments where all test items require good problem-solving skills.

In the spring before the study was undertaken, the instructor decided that a change was needed. The hypothesis was that students' learning outcomes (exam scores) could be improved by adopting a student-centered instructional approach, in which class time was focused on problem-solving practice rather than delivering lectures. In-class activities were developed for one of the two sections of the course to provide students with more problem-solving opportunities and ultimately, to enhance students' critical thinking and problem-solving skills. The other section remained as a lecture-based course. Both sections were taught in auditoriums.

Transformation

The transformation of the course was a collaborative effort between the course instructor and an instructional designer from the university's Office of Teaching, Learning & Technology, and was supported by the university's Large Lecture Transformation project. The transformation took seven months and included course planning, design, and development phases. During the planning phase, students' needs were reviewed, and instructional strategies to better meet them were identified. It was concluded that giving students more practice would be the most direct approach to improving their problem solving, and whenever possible, immediate feedback about students' answers and specific guidance should be provided.

To acomplish these objectives without reducing the course content or increasing the student workload, the following was decided during the design phase: (1) Lectures would be limited to 10-minute summary of key concepts to free 40 minutes for problem solving per class, (2) Omitted lecture details and examples would be covered in online video lectures to ensure continued availability, (3) Problems would be delivered using a web-to-student-smart-device delivery platform to reduce in-class overhead, (4) Answers would be scored in real time and the scores counted toward final grades to encourage attendance and problem ownership, (5) Multiple attempts would be permitted, (6) Collaborative learning among class mates and seeking help from the instructional staff would be encouraged, (7) Different parameterizations of each problem would be delivered to each student to ensure strategy, as opposed to answer, sharing, (8) A course website listing assigned readings, lecture videos, and simple pre-class problems would be posted for students' preparation, and (9) The content difficulty and frequency of homework and exams would remain the same as the lecture-based section to maintain course continuity.

The leveraging of existing resources played an essential role in the development phase. To avoid from-scratch development of a problem delivery platform, a textbook publisher's homework delivery and assessment platform, MasteringEngineering™, was repurposed for real-time in-class problem delivery. Similarly, to reduce the number of online videos that had to be created, permissions were secured to link to existing public-domain circuits lecture and problem-solving videos. Most development efforts were focused on ordering the course topics, crafting 44 10 minute-powerpoint mini-lectures, modifying or creating, and coding 517 MasteringEngineering problems, and creating a course website to organize materials for each class and the links to all this content. The actual coding of the problems was completed in XML (Extensible Markup Language) using proprietary publisher editors (Pearson, 2015). Two undergraduate students supported this effort.

In the final stage of the development phase, the instructor and instructional designer trained all teaching assistants to effectively respond to questions and to coach students during class, discussion sections, and office hours. A comprehensive research assessment plan was designed to measure the effectiveness of the student-centered approach to student engagement, motivation, and learning outcomes compared to the lecture-based section. Approval for the research was obtained from the university's Institutional Review Board.

Student-centered Section

The key differences between the original lecture-based and transformed student-centered sections' course structures are summarized in Table 1. The most significant changes are the reduction of in-class lecture time from 50 to 10 minutes to allow 40 minutes for problem-solving and the

Table 1. Lecture-based vs. Student-centered Course Structure.

	Lecture-based	Student-centered
Pre-class	Text readings	Text readings Lecture videos (6-18 minutes) Optional supplemental materials 3-6 optional pre-class problems (web distributed and scored)
In-class	Lecture (50 minutes)	Lecture (10 minutes) 4-6 graded in-class problems (web distributed and scored)
Post-class	Q&A in a weekly discussion 6-7 graded weekly homework problems (hand scored)	Q&A in a weekly discussion 6-7 graded weekly homework problems (web distributed and scored)
Assessment	2 midterms and 1 final (80%) Homework (20%) (12 assignments, lowest 2 dropped)	2 midterms and 1 final (75%) Homework (15%) (12 assignments, lowest 2 dropped) In-class problems (10%) (43 assignments, lowest 6 dropped)
Teaching assistants' role	Lead a weekly discussion Grade homework Provide office hours	Lead a weekly discussion Help students during class Provide office hours
Essential Technology	None	MasteringEngineering™ Robust classroom Wifi Wifi capable student smart devices
Classroom	Auditorium	Auditorium

adoption of the web-based feedback platform, MasteringEngineering, for distributing and scoring all problems in real time.

Additional differences included: the posting of short lecture videos covering the details and examples cut when the in-class lectures were shortened; the posting of optional pre-class problems similar to in-class problems to enable students to better prepare for in-class problem solving; reducing the grade weighting of homework so that credit could be given for in-class problem-solving; and requiring all students to secure MasteringEngineering licenses and bring Wi-Fi enabled smart devices to class to ensure they had access to MasteringEngineering. All teaching assistants were freed from grading weekly assignments. Instead, they all helped students during every class. The instructor ran a weekly 30-minute meeting with all teaching assistants to provide guidance on teaching the week's topics. The teaching assistants used this time to share any problems that occurred in class and their discussion sections and to address strategies to solve them. For the sake of course continuity, the course content, the content difficulty, the frequency of homework assignments and exams, and the discussion sections' question and answer format were left unchanged.

The effect of these changes was to provide students substantially more opportunities for problem-solving practice and to enrich the available problem-solving support. Over the 15-week semester, students in the lecture-based section had the opportunity to solve roughly 75 homework problems. Students in the student-centered section were likewise assigned a similar number of homework problems but also had the opportunity to solve 442 additional problems. Of these additional problems, 232 were assigned in class, and 210 were posted for optional pre-class work. On average, at least 164 of the in-class problems were attempted (opened). That is, on average, students in the student-centered section attempted at least twice as many problems.

In addition, students received immediate feedback whether their answer was correct or not after every answer submission. This immediate feedback enabled them to more quickly recognize when they were on the wrong track and seek help. In the event of an error, they usually received an additional constructive error message such as, "*Check your signs*" or "*The answer does not depend on* V_3". Students were limited to three answer submissions per problem without penalty in class and penalized 20% per answer submission per problem on homework problems. No limits or penalties were imposed on the pre-class problem answer submissions since they were optional.

More importantly, students were encouraged to work together and to seek as much help from the circulating teaching assistants and instructor as needed. Even though students were graded individually, collaboration worked well because all problems were coded to parameterize each student's problems differently. Therefore, regardless of who provided the help, most discussions had to be about how the problems could be solved instead of specific answers, because the answers were all different. All students benefited from these interactions because students either affirmed that their understanding was good enough to craft an explanation or solve a specific problem, or that they were still confused and needed more help. Importantly, students received this feedback in real time, problem after problem and class after class, as they practiced their problem solving, not just when their homework or exams were graded as they would have in the lecture-based section.

Figure 1 illustrates how students interact with MasteringEngineering in practice. To begin, students open a MasteringEngineering problem on their smart device—an iPhone 5s in this case (Figure. 1(a)). From their pre-class preparation or the 10-minute mini-lecture at the beginning of the class, they recognize that they can solve Part A using Ohm's law. If they do not recognize this, they can request a hint from MasteringEngineering, or seek help from peers, the circulating teaching assistants, or instructor. They then derive the Ohm's law expression for the desired current in their notebook (Figure, 1(b)) and enter it into MasteringEngineering as an expression using their iPhone's virtual keyboard (Figure. 1(c)), not realizing that they have flipped the sign of the rightmost voltage source. Knowing all correct algebraically equivalent expressions, MasteringEngineering scores the student's first submission as incorrect and informs them that they have likely made a sign error (Figure. 1(d)). At this point, the student can again request the hint from MasteringEngineering if they have not already done so or attempt to find the error on their own, or with help from a classmate,

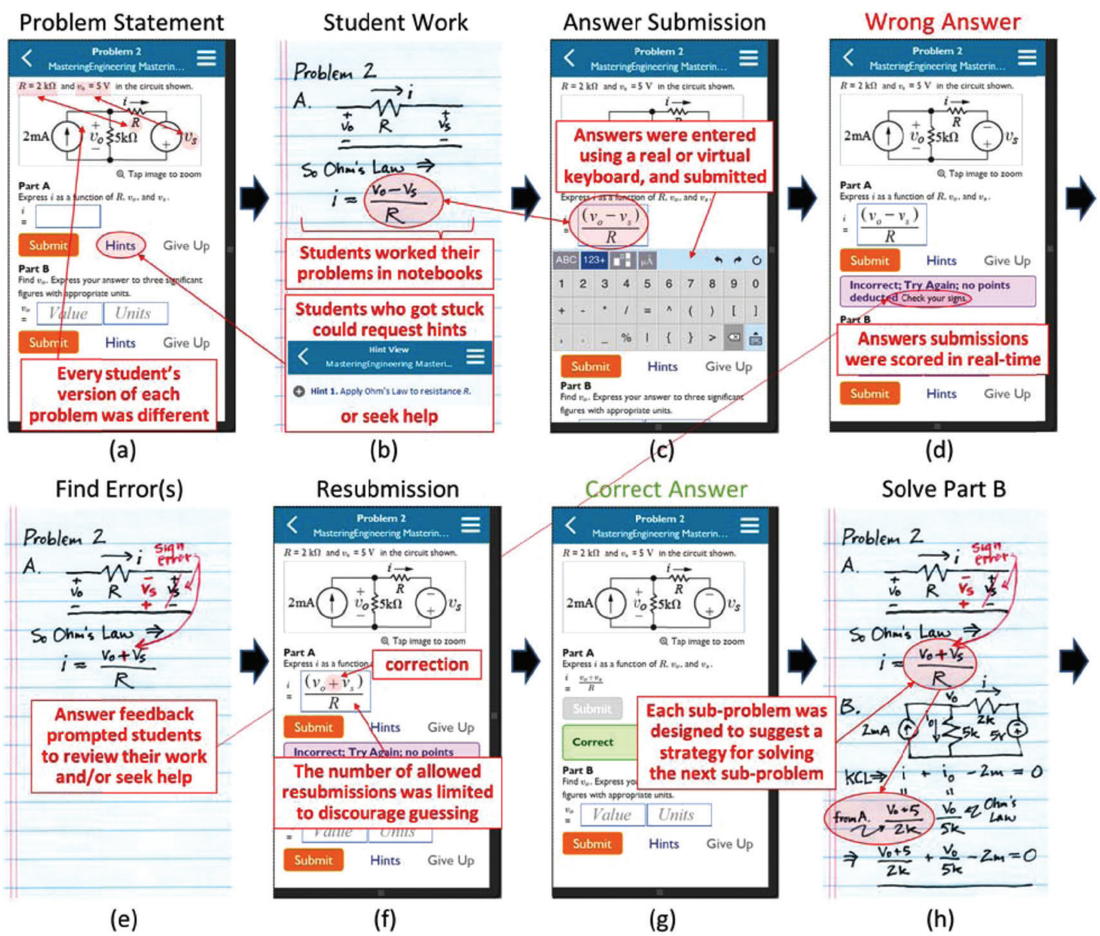

Figure 1. Annotated illustration of a student's interaction with the MasteringEngineering™ platform on an iPhone 5s.

teaching assistant, or the instructor. Once they discover their error (Figure. 1(e)) and submit their revised answer (Figure. 1(f)), they learn immediately from MasteringEngineering that it is correct (Figure. 1(g)). This builds confidence, especially when they realize in their notebook solution to Part B that the answer to Part A can be used to solve Part B (Figure. 1(h)).

METHOD

The goal of this study was to investigate the effectiveness of a student-centered approach in the transformed electrical circuits course. The principal hypothesis was that, even in an auditorium-taught course, students' learning outcomes (exam scores) could be improved through in-class practice and immediate feedback in collaborative learning environments. Additionally, students' engagement, satisfaction, and motivational constructs, including students' self-efficacy, intrinsic value, and test anxiety, were compared across the two sections.

Participants

Students selected one of the two course sections. A week before the semester started, the instructor of the student-centered section sent students an email explaining the different course structure and the requirement that a smart device be brought to every class. Thus, students had an opportunity to change sections. The students in the lecture-based section did not have access to any of the problems delivered by the MasteringEngineering platform.

Two hundred and forty-three students, 127 of them from a lecture-based section, and 116 from a student-centered section participated in the study. This corresponded to 79% of the total enrollment of both sections. Of the 243 students, 74.9% were male and 72.4% were sophomores. The percentage of male and sophomore students was not significantly different between the two sections.

Procedures

Three surveys were administered in each section during the 15-week semester. The first survey was administered during the 2nd week of the semester to assess students' initial self-efficacy, intrinsic value, and test anxiety. The second survey was administered during the 7th week of the semester, immediately following the students' first midterm exam. It assessed students' perceptions of the helpfulness of the class meetings and the technology used in the class. The third survey was completed at the end of the semester and assessed students' end-of-semester perceptions of the helpfulness of class meetings as well as their engagement, satisfaction, self-efficacy, intrinsic value, and test anxiety. The second and third surveys also asked students to identify the most helpful and challenging aspects of the course.

Students' demographic information, test scores, homework scores, and prior learning outcomes (cumulative graduate point average and ACT math scores) were collected after the semester was over. Participation in the study was voluntary, and participants received a small cash compensation for the time that they spent completing surveys.

Measures in Self-reported Surveys

Self-efficacy, intrinsic value, and test anxiety were measured by 22 items adopted from the Motivation Beliefs Questionnaire (Pintrich & De Groot, 1990). The engagement measure consisted of three subscales: behavioral, emotional, and cognitive. The behavioral and emotional engagement subscales were adopted from Skinner, Kindermann, and Furrer (2009), and the cognitive engagement

Table 2. Measures.

Instruments	The number of items	Cronbach's alpha for this study	Sample item
Behavioral engagement	5	.84	When I'm in this class, I listen very carefully
Emotional engagement	5	.94	This class is fun
Cognitive engagement	4	.91	When reading for this class, I try to explain the key concepts in my own words
Self-efficacy	9	0.89 (pre) 0.93 (post)	I am sure I can do an excellent job on the problems and tasks assigned for this class.
Intrinsic value	9	0.93 (pre) 0.89 (post)	It is important for me to learn what is being taught in this class.
Test anxiety	4	0.93 (pre) 0.90 (post)	I worry a great deal about tests.
Preparedness	1	NA	I prepare for the class before I come to lecture (e.g., reading textbook, doing practice problems)
Learning from the mistakes	1	NA	I learn from my mistake while I work on the problems.
Improved problem-solving skills	1	NA	My problem-solving skills have been improved through this class.
Improved critical thinking skills	1	NA	My critical thinking skills have been improved through this class.
Satisfaction 1	1	NA	I would like to take another course in Electrical Engineering.
Satisfaction 2	1	NA	I am more interested in electric circuits than I was before I took this class.
Satisfaction 3	1	NA	I would recommend this course to my friends.
Satisfaction 4	1	NA	What was your overall satisfaction with this course?

Notes. Pre = the survey administered at the beginning of the semester, Post = the survey administered at the end of the semester. All questions except preparedness and learning from mistakes offered a 7-point scale ranging from 1 (strongly disagree) to 7 (strongly agree). Preparedness and learning from the mistakes offered a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). Satisfaction items offered a 7-point scale ranging from 1 (very unsatisfied) to 7 (very satisfied).

subscale was adopted from Senko and Miles (2008). The authors developed questions to assess students' perceptions of their preparedness prior to class, learning from their mistakes, and improvement of their problem-solving and critical thinking skills, and additionally, developed four questions to assess students' satisfaction with the course. Table 2 summarizes the measures that were used.

RESULTS

Learning Outcomes

The major performance benchmarks for both sections were students' scores on three exams—two midterms and a final. These exam scores accounted for 75% of each student's course grade. The

Table 3. Descriptive Statistics for the Test Scores of the Matched Items, Cumulative GPA, and ACT Math.

	Lecture-based		Student-centered (transformed)	
	N	M (SD)	N	M (SD)
All participants				
Exam 1	124	36.33 (17.91)	111	45.63 (17.89)
Exam 2	124	35.65 (13.27)	110	45.73 (14.74)
Final	124	30.77 (13.79)	110	41.59 (14.84)
Cum_GPA	124	3.10 (.50)	111	3.41 (.44)
ACT Math	111	28.22 (3.07)	102	29.47 (3.26)

Note. The maximum points were 75 for the first midterm and final and 70 for the second midterm. CUM_GPA = the cumulative grade point average before taking the electrical circuits course.

exam items covered the entire range of learning objectives for the course, and no problem could be correctly answered without problem-solving. All exams had 18 questions, and each question was worth 5 points. Although the two sections' entire exams were not identical, 15 of 18 first and final exam questions and 14 of 18 second exam questions were the same on both sections' exams. Only scores on matched exam questions were included in the analysis of learning outcome comparisons to maintain the accuracy of the results.

Tables 3 lists the means and standard deviations of the exam scores, prior cumulative grade point average (GPA), and ACT math score for all participants. The mean scores of all tests for the student-centered section were higher than those for the lecture-based section. But as the mean of prior cumulative GPA and ACT math scores in the student-centered section were also significantly higher than the mean of those in the lecture-based section, at least some of this difference may be attributed to sampling bias.

Table 4 summarizes the results of the three linear regressions predicting the exam scores. Prior cumulative GPA and ACT math score were included as covariates along with the section variable in each regression model to better account for GPA and ACT math score bias. The model explained

Table 4. Results of the Linear Regressions Predicting the Exam Scores.

	M1				M2				Final			
Predictor	R^2	ES	SE	p	R^2	ES	SE	p	R^2	ES	SE	p
Model	0.34				0.40				0.37			
Cum_GPA		17.9	2.4	.000		15.8	1.8	.000		14.5	1.9	.000
ACT Math		0.3	0.4	0.45		-0.2	0.3	0.6		0.05	0.3	0.9
Section		4.3	2.2	.06		5.9	1.7	.001		6.36	1.8	.001

Note. CUM_GPA = the cumulative grade point average before taking the electrical circuits course. ES = parameter estimate, SE = standard error.

34 – 40% of participants' exam performance. The results show that the effect of the student-centered section was close to being statistically significant ($p = 0.06$) for the first midterm and was significant for the second midterm and the final exam ($p = 0.001$). That is, the students in the student-centered section obtained significantly higher scores on their second midterm and final exam than the students in the lecture-based section after controlling for their GPA and ACT scores.

Self-reported Survey

The results of statistical analyses comparing the effects of lecture-based versus student-centered instruction on student engagement, self-efficacy, intrinsic value, and anxiety are summarized in Table 5. The mean of students' engagement level in the student-centered section was 4.5, whereas it was 3.88 in the lecture-based section on a 7-point scale. All three types of engagement in the student-centered section were consistently higher than those in the lecture-based section. In particular, the

Table 5. Results of Independent t-Test & Descriptive Statistics for Student Self-reported Engagement, Satisfaction, Self-efficacy, Intrinsic Value, and Test Anxiety.

	Lecture-based		Student-centered (transformed)		
	N	M (SD)	N	M (SD)	t
Engagement (post)	92	3.88 (1.23)	92	4.51 (1.11)	3.63***
Behavioral	92	4.49 (1.16)	92	5.37 (1.10)	5.24***
Emotional	92	3.20 (1.56)	92	3.78 (1.41)	2.65**
Cognitive	92	3.96 (1.52)	92	4.34 (1.57)	1.70
Self-efficacy (pre)	127	5.67 (.68)	116	5.52 (.83)	-1.62
Self-efficacy (post)	93	4.25 (1.13)	92	4.79 (1.28)	3.07**
Intrinsic value (pre)	127	5.41 (.93)	116	5.35 (.96)	-.47
Intrinsic value (post)	93	4.03 (1.23)	92	4.43 (1.32)	2.14*
Test anxiety (pre)	127	3.64 (1.65)	116	3.87 (1.51)	1.10
Test anxiety (post)	93	4.40 (1.63)	92	4.21 (1.66)	-.77
Preparedness	93	3.25 (1.47)	91	4.47 (1.51)	5.58***
Learning from mistakes	93	2.52 (1.64)	92	4.55 (1.97)	7.64***
Improved problem-solving skills	93	3.76 (1.47)	92	4.37 (1.57)	2.71**
Improved critical thinking skills	93	3.74 (1.52)	92	4.43 (1.61)	3.01**
Satisfaction 1	92	2.98 (2.22)	91	3.19 (2.29)	.62
Satisfaction 2	92	2.82 (1.98)	91	3.44 (2.14)	2.05*
Satisfaction 3	92	2.47 (1.79)	91	2.85 (2.08)	1.3
Satisfaction 4	92	3.28 (1.68)	91	3.34 (1.93)	.22

Note. All variables except preparedness and learning from mistakes in the self-reported survey were measured using a 7-point Likert-type scale. Preparedness and learning from mistakes were measured using a 5-point Likert-type scale. "pre" indicates that the survey was administered at the beginning of the semester. "post" indicates that the survey was administered at the end of the semester.
*$p < .05$, **$p < .01$, *** $p < .001$

behavioral and emotional engagement in the student-centered section were significantly higher than those in the lecture-based section.

Students' self-efficacy, intrinsic value, and test anxiety were measured at two different times (beginning and end of the semester). The pre self-efficacy and intrinsic value were higher than the post measures, and the pre test anxiety was lower than the post measure in both sections. The results of t-test indicated that there were no significant differences in pre self-efficacy and intrinsic value between the two sections. However, the post self-efficacy ($t = 3.07$, $p < .01$) and intrinsic value ($t = 2.14$, $p < .05$) in the student-centered section were significantly higher than those in the lecture-based section. The post test anxiety between the sections was not significantly different.

At the end of the semester, we asked students about their level of the preparedness for each class and whether they learned from their mistakes and the feedback received while solving the problems. The students in the student-centered section reported that they were significantly better prepared for class ($t = 5.58$, $p < .001$) and learned more from their mistakes and the feedback received ($t = 7.64$, $p < .001$) than the students in the lecture-based section. We also asked students' perceptions of the improvement of their problem-solving and critical thinking skills through the electrical circuits course. The students in the student-centered section reported significantly higher perceptions of the improvement of these skills than the students in the lecture based section ($t = 2.71, 3.01$, $p < .01$). However, students' satisfactions with the course in both sections were relatively low. Among the four satisfaction questions, the students in the student-centered section expressed increased interest in electrical circuits compared to the students in the lecture-based section after taking the course, and this difference was statistically significant between the two sections. However, no significant differences between the sections were found for the other satisfaction items.

Additionally, we asked students how often they attended their class during a typical week and their perceptions of the helpfulness of the class after the 7th week (second survey) and at the end of the semester (third survey). The results of a paired t-test indicated that the frequency of attending class and students' perceptions of the helpfulness of the class in the lecture-based section had decreased significantly by the end of the semester. However, there were no significant changes in attendance and perceptions between the 7th week and the end of the semester in the student-centered section (Figure 2).

The students in the student-centered section also reported significantly more study hours per week than the students in the lecture-based section on all three surveys (Figure 3). However, the mean of the study hours in the student-centered section did not exceed the six weekly study hours typically recommended for three-semester-hour courses at most universities.

Finally, students were asked to share what they found to be the most helpful and challenging aspects of their course in the second and third surveys. Not surprisingly, issues related to learning

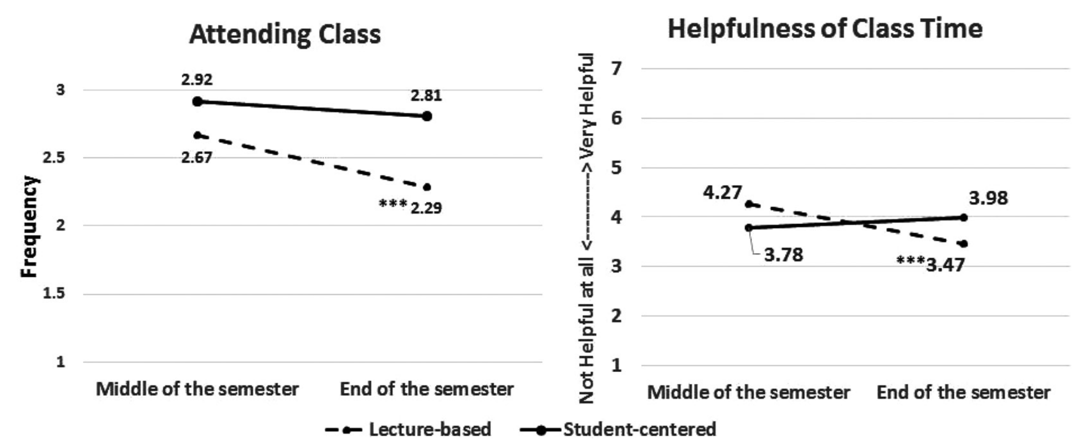

*Figure 2. Students' self-reporting of their frequency of attendance (times per week) and their perceptions of the helpfulness of the class meetings. The class met three times per week. *** p < .001*

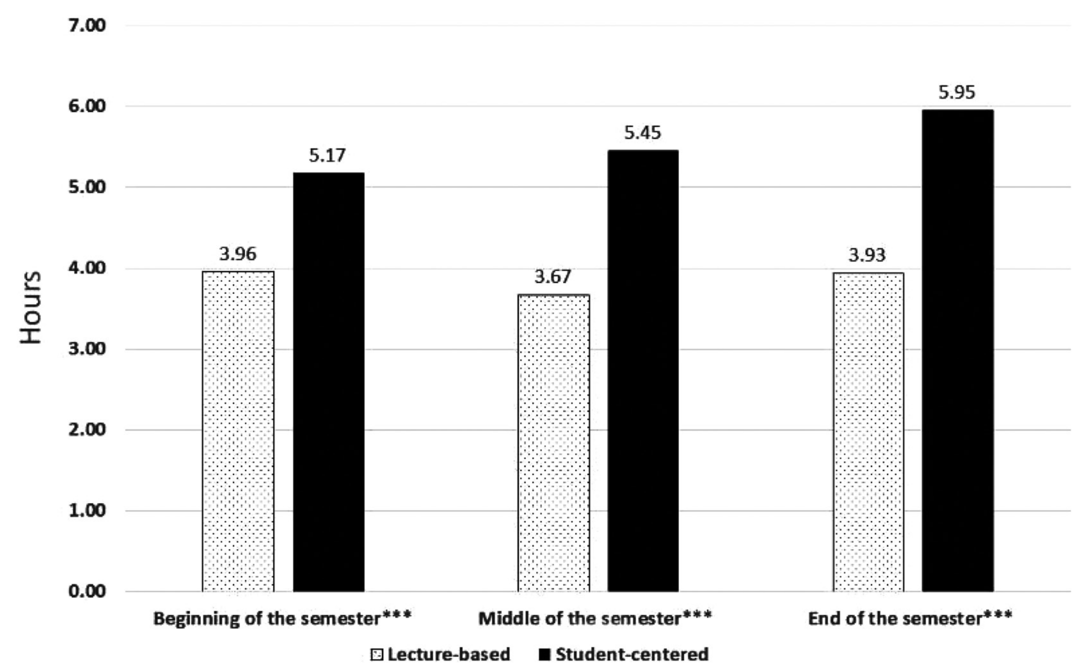

Figure 3. Students' self-reported study hours outside of class in a typical week.

the subject were mentioned most frequently although the specific challenges cited were somewhat different between the two sections. In the lecture-based section, the main theme was ‘hard to keep up in lecture’ whereas ‘limited time to prepare for each class’ and ‘completing all problems in the given time and space’ were the main themes in the student-centered section. In particular, many students reported that an auditorium did not provide proper learning space for student-centered learning. The following are direct quotes extracted from the students’ survey responses.

“I am having a hard time figuring out how to solve the problems. Concepts are not too bad but when I get to the problems I am stuck” (a student from the lecture-based section)

“Trying to listen to what the teacher is saying in class while writing down the solution to the problem on the board (is challenging). Trying to understand how to do problems outside of class, on my own (is challenging).” (a student from the lecture-based section)

“Feeling stressed during class trying to finish in-class assignments. I felt the lecture hall we were in was not adequate for a class that required us to work problems in class every day.” (a student from the student-centered section)

“Having to prepare ahead of time is challenging” (a student from the student-centered section)

“The setting (is challenging). The lecture hall and massive class size made teamwork very difficult” (a student from the student-centered section)

The common themes regarding the most helpful aspect of the course in both sections included teaching assistants’ and peers’ help, example problems, and homework problems. Additional themes in the student-centered section were ‘working through many problems in class’ and ‘preparing for each class.’ The following are additional direct quotes extracted from the students’ survey responses.

“working with classmates outside of lecture was helpful” (a student from the lecture-based section)

“doing extra problems in the book was helpful” (a student from the lecture-based section)

“Completing so many problems helps me understand the concepts much better.” (a student from the student-centered section)

"The rigor associated with preparing for each class has certainly made preparing for the exam very easy." (a student from the student-centered section)

"The most helpful aspect is that I get to work on more problems and get immediate feedback." (a student from the student-centered section)

DISCUSSION

The significantly higher exam performance in the student-centered compared to the lecture-based section is consistent with previous research findings (e.g., Freeman et al., 2014; Russell et al., 2016). However, we noticed that the effect of the student-centered approach on first midterm performance was not as significant as it was for the other two exams. This result could perhaps be attributed to the fact that many engineering students learn the basics of electrical circuits that are the focus of the first exam in the latter part of their high school physics and second college physics courses. Therefore, the instructional model has less impact on the first exam. Alternatively, the result might suggest that the benefits of active learning developed during the beginning of the semester might not be evident until the time of the second exam. Previous research indicates that for students to succeed in student-centered courses, they must change their behavior, for instance, by interacting with course material and obtaining some level of conceptual and procedural knowledge before each class to maximize learning during the class meeting (e.g., McCallum et al., 2015). Although the student-centered instructor provided specific guidance about what it would take to succeed in the class at the beginning of the semester, students seemed to take some time to internalize the guidance and change their behavior. This may have been why we did not detect a significant difference in the first exam scores between the two sections.

The students' self-reported surveys also provided insights about how they engaged and how they perceived the class meetings differently in the two sections. First, consistent with past studies (e.g., Gross et al., 2015), the students in the student-centered section reported a higher level of preparedness for class than the students in the lecture-based section. Second, the self-reported behavioral and emotional engagement in the student-centered section were significantly higher than those in the lecture-based section. It is typical for student attendance to decrease with time in large lecture courses, and this decrease was observed in the lecture-based section. In contrast, attendance in the student-centered section did not drop over the semester. The fact that 10% of the student-centered section's grade could only be obtained in class helped keep the student-centered section's attendance consistent. But it appears there was another factor. While students' perceptions of the helpfulness of class meetings of the lecture-based section was higher than those of the student-centered at the beginning of the semester, it reversed at the end of the semester. This could also be a reason why students' attendance in the student-centered section was sustained until the end of the semester while students' attendance in the lecture-based decreased. The students in the student-centered expressed that solving many problems during class was the most helpful aspect of the course even though they found finishing them in time stressful.

Interestingly, students' motivational components (self-efficacy and intrinsic value) were higher at the beginning of the semester than at the end of the semester in both sections. Students seemed to overestimate their self-efficacy and intrinsic value at the beginning of the semester. The initial self-efficacy and intrinsic value measured at the beginning of the semester were not significantly different between the sections. However, those measured at the end of the semester were significantly different. Intrinsic value and self-efficacy in the student-centered section were significantly higher than those in the lecture-based. According to Bandura (1997), self-efficacy refers to "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" (p. 3). As successfully solving circuits problems certainly builds students' circuits problem-solving self-efficacy, the difference is not surprising. Through in-class practice, peer collaboration, immediate answer feedback, and on-demand assistance from instructional staff, the student-centered section provided students with more opportunities to practice skills and achieve problem-solving success, which could explain the student-centered section's higher self-efficacy compared to the lecture-based section.

Despite the fact that students' engagement and learning outcomes in the student-centered section were significantly higher than those in the lecture-based section, students' satisfaction with the course was relatively low in both sections. This result could be related to the findings of a previous study regarding students' negative perceptions of the self-discipline and responsibility expected in student-centered courses (McCallum et al., 2015). As seen in the results, the students in the student-centered section reported that they prepared more and studied longer than the students in the lecture-based section. One of the major reported challenging aspects of the student-centered section was "preparing adequately before each class." This suggests that the students in the student-centered section took more responsibility for their learning and consequently changed their behaviors. Further, the inadequate classroom for active learning was mentioned as another challenging aspect in the student-centered section. These challenges might be related to relatively low satisfaction with the course even though they achieved higher test scores.

Lastly, although some studies noted the potential challenge of maintaining course content in student-centered learning (e.g., Yazedjian & Kolkhorst, 2007), that was not an issue in the student-centered section of this study. Both sections successfully completed the same content. What likely made this possible was the use of a problem platform for delivering and scoring all in-class problems in real time to avoid the "activity overhead" that sometimes slows down active learning courses.

LIMITATIONS AND FUTURE DIRECTIONS

This study provided robust evidence of the benefits of a student-centered instructional approach compared to lecture-based teaching in a large electrical circuits course. The student-centered approach seemed to impact students' behaviors, and students valued the in-class problem-solving activities in collaborative learning environments. However, the study lacks the qualitative data to identify the origins of these benefits. It is not well understood, in particular, how the collaborative learning environment helped student learning. Students discussed problems, asked questions of each other, and got help from the teaching assistants and instructor during class. However, the students' roles (e.g., who asked, who answered), the nature of their questions, and the discourse that led to positive learning outcomes remain unclear. Further, although all exam problems were designed to assess specific problem-solving objectives and therefore, the aggregate test results are certainly correlated with problem-solving ability, it is difficult to assess direct problem-solving ability based on the results of exams.

Additionally, students in the student-centered section expressed concerns about the adequacy of the auditorium learning space for effectively collaborating with peers and interacting with teaching assistants and instructors. Further research will be needed to investigate whether students' learning outcomes would show even more improvement in other learning spaces (e.g., active learning classrooms) with the same instructional approach, and to determine which specific activities and constructs most significantly impact learning, and which activities are transferable to other courses.

SUMMARY

This study compared engagement, satisfaction, and learning outcomes (exam scores) of students who enrolled in a student-centered section versus a traditional lecture-based section of the same electrical circuits course at a large public university. The aim of the research was to understand the potential benefits of a student-centered instructional model that replaces lecture with problem-solving practice using a web-based feedback system in class.

To maximize the number of problems that could be solved in class, the instructor in the student-centered section repurposed a homework delivery platform for in-class use and limited lecture to 10 minutes per class. To make up for the lost lecture time and help students better prepare for class, the instructor posted detailed lecture videos, supplemental materials, and optional practice problems on the course site before each class. At the beginning of the semester, the instructor trained teaching assistants how to help students solve problems in class and how to lead discussion sections, and provided on-going support via weekly meetings throughout the semester.

All students in the student-centered section were required to bring Wi-Fi capable devices to class to engage with the circuits problems. After an initial 10-minute "mini-lecture," students engaged with four to six circuits problems for the remainder of each 50-minute class period. Over the course of the semester, the student-centered section offered students 442 additional opportunities to solve problems (232 assigned in class and 210 posted for optional pre-class problems) compared to the lecture-based section. On average, students in the student-centered section attempted at least twice as many problems as those in the lecture-based section.

Whenever students submitted an answer, the system provided an indication of whether it was correct or not. When it was incorrect, specific feedback suggested possible next steps. Students also could request hints from the system or seek help from their peers, teaching assistants, or the instructor. Students were encouraged to collaborate with peers. Due to different parameterizations of each problem, each student had different answers. Therefore, the collaboration led them to discuss strategies as opposed to specific answers.

The results of regression analyses indicated that the students in the student-centered section achieved significantly higher test scores on the matched exam items of the second midterm and final exam than the students in the lecture-based section after controlling for their prior learning outcomes (cumulative GPA before taking the circuits course and ACT math scores). Students in the student-centered section reported preparing better for each class, attending class more frequently throughout the semester, and spending more study hours each week than students in the lecture-based section. Students in the student-centered section were also more engaged in the course, on average, than students in the lecture-based section. The students in the student-centered section reported that solving many in-class problems with peers and the instructional staff were helpful to their learning even though it was stressful to prepare for each class and to complete the assigned problems during class. Students also reported that the auditorium did not provide proper space for student-centered learning, in particular, for collaboration with peers and interactions with the instructional staff.

Although the study provided robust evidence of the benefits of a student-centered instructional approach compared to lecture-based teaching in a large electrical circuits course, its limitations prevent identification of the origins of these benefits. Further research is suggested to determine which specific activities and constructs of student-centered instruction significantly impact learning, which of these activities are transferable to other courses, and whether the same student-centered instructional approach would achieve better learning outcomes in active learning classrooms than in auditoriums.

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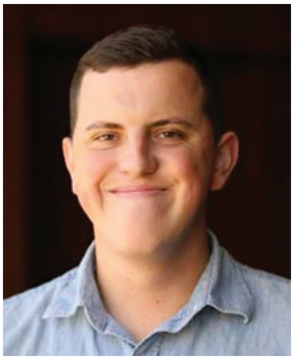

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