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Looking Ahead: Advancing Engineering Education through Case Studies in Introductory Courses

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INTRODUCTION

Engineering is one of the most practical fields. Regardless of the discipline, engineering students require hands-on experiences during their undergraduate studies. In addition to the standard laboratory courses, there are multiple ways of integrating the hands-on experience into undergraduate engineering curricula. Projects (Bernhard and Carstensen 2003; Cartensen and Bernhard 2009), problem-based learning (PBL) (Yadav, Subedi and Lundeberg 2011), virtual experimentation (VE) (Kolloffel and Jong 2013; Finkelstein 2005; Zacharia 2007), case study analysis (Bull, Jackson and Lancaster 2010; Campbell, Saffih and Nigim 2006), and field visits are some of those techniques. This article provides the results of the hands-on learning experience provided by case study analysis with embedded virtual experimentation at an introductory level course. Each case presented a common problem or a misconception in electrical circuits.

Case studies have been used in disciplines such as business, law, and medicine (Davis and Yadav 2014). Starting in the mid-1900s, problem-based learning became a part of STEM majors (Davis and Yadav 2014). In engineering, case study analysis is widely used in engineering ethics training and dispute resolution (Bass, Beecham and Noll 2018; Fleddermann 2000; Scharnell and Sabol 2018). In electrical engineering, case studies were implemented in junior, senior, or graduate-level electrical circuits courses focused on a single electrical circuitry concept (Fan, Wang, Han and Sun 2013; Jenko 2012; Prabhu, Nande, Shukla and Ade 2016; Prasad and Punekar 2019; Qu and Wang 2016; Rutkowski and Moscinska 2011; Suyono, Hasanah, Kuncoro and Mokhlis 2017; Yundong, Xiaoming, Erzhi and Licheng 2000).

This paper presents the implementation of a case study analysis in an introductory level electrical circuits course. According to the author's knowledge, this is the first time hybrid implementation of a case study analysis with problem-based learning (PBL) and virtual experimentation (VE) in an introductory level electrical circuits course globally. The student body of this course was comprised of a diverse group of engineering disciplines including, 12 from electrical engineering, 18 from mechanical engineering, 3 from electrical-mechanical engineering, one from cybersecurity, and 4 transfer students with discipline not yet assigned. In terms of graduation standing there were 14 sophomores, 17 juniors, and 7 seniors. As mentioned above, this was an introductory electrical course, and a significant number of juniors and seniors were from non-electrical engineering majors.

The following sections illustrate the cases, feedback collection method, the results from this initial implementation, and next steps.

METHODS

Cases

Students received five cases by the end of the 9th week of the fall 2020 semester. Out of the five cases, each student picked one case to analyze for three weeks. Students chose the case studies according to their preferences. Together with the cases, they received the following steps on analyzing the cases. Each case was based on a common problem in electrical circuits.

1. Read the case study
2. Identify the issue or the situation
3. Propose your solution or the explanation
4. Provide calculations and/or simulations (VE) supporting your explanation
5. Prepare a 3-page case study analysis report

The cases were uniquely designed for this course by the instructor of the course (author of this paper). The five cases covered the entire scope of the course. The storyline of the cases had three hypothetical people with gender-neutral names who needed help understanding a concept or an implication. The case study analysis described the process of guiding those three hypothetical people when they ask for assistance understanding the situation.

Case 1: Implications of Zero Resistance

Concept: Thevenin's equivalence voltage and resistance from a circuit diagram.

Target issue: Based on the circuit configuration, the Thevenin's resistance would be zero. The next step was to determine the load resistance that needed to be connected in series with the equivalence circuit to deliver maximum power using the maximum power transfer theorem, given the zero equivalent resistance.

Virtual experiment: Students simulated an electrical circuit with varying resistor-loads and observed how the maximum power across the load changes with varying load resistances. They also needed to check the power when the load resistance is zero.

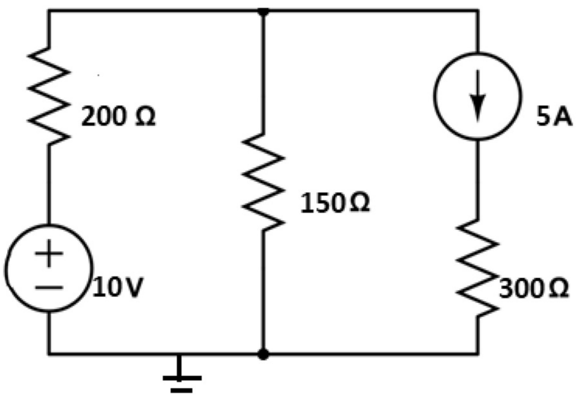

Figure 1. The circuit diagram given in the case to find the voltage difference across the current source.

Case 2: Voltage Difference Across a Current Source

Concept: The effect of a current source on loop (or mesh) analysis.

Target issue/misconception: The voltage difference across its current source is unknown but it is not zero. This is an issue when it comes to analyzing a circuit using loop analysis. Therefore, in this case, students received a circuit diagram with two loops shown in Figure 1, and it asked students to apply loop analysis and show that it is incorrect to assume the voltage difference across a current source to be zero.

Virtual experiment: Students simulated the circuit and measured the correct voltage value across the current source.

Case 3: Impedance of Inductors and Capacitors

Concept: Impedance, and how it varies with frequency using calculations and simulations. In this case, students received a widely used R-L-C filter circuit.

Target analysis: Total impedance changes with frequency. Besides, it asked students to study the source behavior of a capacitor during positive and negative half cycles of a sinusoid.

Virtual experiment: Students simulated the circuit with inductors and capacitors, to observe how the circuit impedance changes with varying source frequencies and the behavior during the two half-cycles.

Case 4: Three-Phase Circuit

Concept: A balanced three-phase transmission circuit.

Target analysis: The concept of 'phase' and study the balanced three-phase network. Students were familiar with three-phase transmission lines, but they were not familiar with the configuration.

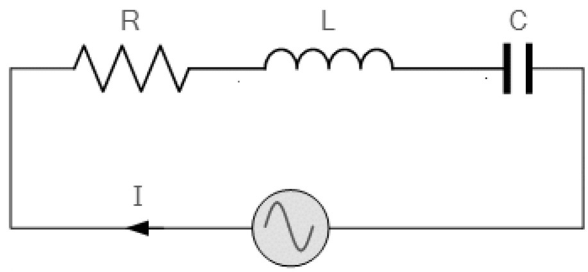

Figure 2. The circuit diagram for phase analysis of reactive components.

Virtual experiment: Students simulated the circuit and observed the behavior of a balanced three-phase network.

Case 5: Phase-shift, Leading and Lagging

Concept: Resistor- inductor-capacitor (RLC) circuit shown in Figure 2, and explore the concept of phase-shifting.

Target analysis: The leading and lagging phases of current and voltage through inductors and capacitors.

Virtual experiment: Students simulated an RLC circuit and observed the phase shift between voltages and current across each circuit element.

FEEDBACK COLLECTION

Upon submission, students gave their feedback on case studies. The feedback form contained the following five statements where they rated their experience on a scale of 1- strongly disagree to 5- strongly agree. Students had the option to be anonymous and also to provide additional comments.

1. Analyzing a case study motivated me to think and/or research beyond the content taught in class.
2. Case studies let me critically analyze the errors/misconceptions on real-world electrical circuits.
3. This case study analysis motivated me to provide facts (calculations, simulations) to solidify my answer.
4. This design project allowed me to develop my writing skills on 'scientific storytelling'.
5. I think case study analysis is an effective method of promoting independent student learning.

PRELIMINARY RESULTS

Out of a class of 38 students, 36 of them completed the assignment. Table 1 shows the selection of cases among the students. The majority of the students selected Case 2: voltage difference across a current source for analysis.

Table 1. Choice of cases among the students.

Case	Number of students
1	4
2	19
3	5
4	5
5	3

The grading scale was based on the instructions given to the students at the beginning of the assignment. The marks allocation was as follows:

a. Understanding the issue 25%
b. Simulations and or calculations 25%
c. Clarity of explanation 25%
d. Implications 25%

Table 2 lists the grades students received.

Table 2. Student's grades for this assignment.

Grade	Number of students
A (>90)	26
B (80 – 89)	9
C (70 – 79)	1
No submission	2

According to the grade distribution, the majority of the students have grasped basic circuit concepts well. Although it is subjective to the student body in each semester, this indicates a possibility of increasing the level of difficulty such that students are expected to analyze more complicated cases.

Out of the 36 students, 31 of them provided feedback to the voluntary post-assignment questions. In the feedback form, students indicated their level of agreement from 1 (strongly disagree) to 5 (strongly agree). The questions and percentage of student responses are shown in Table 3. Students had the option to stay anonymous and to also provide additional feedback.

Table 3. Percentage student responses for each question in the feedback form.

#	Question	1: Strongly disagree (%)	2: Disagree (%)	3: Neutral (%)	4: Agree (%)	5: Strongly agree (%)
1	Analyzing a case study motivated me to think and/or research beyond the content taught in class.	6.5	0	25.8	38.7	29
2	Case studies let me critically analyze the errors/misconceptions on real-world electrical circuits.	6.5	6.5	22.6	45.2	19.4
3	This case study analysis motivated me to provide facts (calculations, simulations) to solidify my answers.	3.2	3.2	16.1	29	48.4
4	This design project allowed me to develop my writing skills on 'scientific storytelling'.	0	6.5	32.3	38.7	22.6
5	I think case study analysis is an effective method of promoting independent student learning.	6.5	0	19.4	35.5	38.7

In response to the first feedback question, 21 out of 31 students (68%) agreed that this assignment motivated them to think or research beyond the content taught in class.

For question 2, twenty students out of the 31 (64.5%) agreed that the case study let them critically analyze the misconception on real-world electrical circuits. This point is especially applicable for Case #2 since it directly addressed a misconception. The percentage who agreed with this point matched with the percentage of students who selected Case #2.

In the third feedback question, 24 out of 31 students (77.4%) agreed that the case study motivated them to provide facts such as calculations and simulations to support their answers. Unlike a typical textbook problem where there is a definite answer, making an argument in a case study requires thinking beyond the material delivered in class. Therefore, the use of additional calculations and especially simulations were needed to support the argument.

Nineteen students (61%) agreed that case study analysis (a.k.a design project) allowed them to develop their writing skills in response to feedback question 4.

Twenty-three students (74%) recognized case study analysis as an effective method of promoting independent student learning in the fifth feedback question. Table 4 summarizes the comments received by the students.

Table 4. Additional post-assignement comments from students.

Comments
I enjoyed the use of simulations. It required me to become more comfortable with programs like MultiSim.
I thought the case study was a great assignment to have for ELE 216. I felt that of all engineering classes I have taken, ELE 216 has been the most abstract and hard for me to think about in a practical application sense. This assignment helped me to think about circuits differently and helpful.
It was a good project. Trying to design a new circuit helped me further understand the ins and outs of current and voltage.

Table 5. The proposed rubric for future implementations.

Description	Percentage points
1) Understanding the issue/misconception	15%
a. The student understood the issue or the misconception and articulated it clearly.	
b. The student communicated the analysis plan.	
2) Simulations and/or calculations	40%
a. The student performed appropriate calculations in the analysis process.	
b. The student performed virtual experimentation in the analysis process.	
c. The student gave other examples in the analysis process.	
d. The student used any other analytical tools if needed.	
3) Clarity of explanations	30%
a. The student presented the thought process.	
b. The student demonstrated the results from simulations and/or calculations.	
c. The student provided evidence to solidify the answers.	
d. The student conveyed the conclusions.	
4) Implications	15%
a. Students provided real-world situations where the given analysis can be used.	
b. The student indicated alternative analysis techniques if needed.	

NEXT STEPS

A grading rubric will be given to students during the next implementation. Having a rubric will make the writing and grading process transparent. Future students will receive new cases for analysis. The proposed new rubric is shown in Table 5. The percentage marks allocations are different in the new rubric from the previous, to ensure an unbiased grade distribution by assessing true knowledge.

Based on the comments, students had good knowledge of circuit theory. The grade distribution shown in Table 2 demonstrated that students had a strong grasp of the subject material. If this positive trend continues in future semesters, the level of difficulty of the cases can be increased, providing students more in-depth knowledge in an introductory electrical circuits course.

The new cases will be designed in a similar structure, but with different scenarios. Based on the students' feedback, the virtual experimentation portion will be continued in the cases. The new case studies will be focused more on the practical applications, compared to the theoretical concepts. As seen from Table 1, the majority of the students (19 out of 36) chose case number 2. This preference might be due to the curiosity among students about the voltage difference across a current source, or the familiarity of this misconception. In future implementations, an effort is needed to balance the choice distribution of cases. This can be done by designing the cases with the same level of difficulty, familiarity, and applicability.

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