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Using CATE, the ”Circuit Analysis Tool for Education,” To Facilitate and Complement Peer Learning

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Introduction

Peer learning constitutes a wide range of topics. Boud [1] describes it generally as "students learning from and with each other in both formal and informal ways." The benefits of peer learning have been widely reported in many different contexts. According to Boud [1], peer learning promotes numerous outcomes such as critical inquiry, reflection, teamwork, communication skills and life-long learning. Other published findings address peer feedback [2], peer mentors [3], peer review [4], and facilitating social and academic interaction [5], to cite just a few.

In this study, peer learning involved students working informally outside the classroom . Peer learning was not a course requirement, and no training was provided. Rather, it was encouraged and developed naturally without direct intervention. Peer learning was supplemented using materials generated by CATE, the "Circuit Analysis Tool for Education." Hundreds of CATE problems were available for the class, involving randomized circuits and with equation-by-equation solutions. See an excerpt in Figure 1. CATE learning objectives include mesh and nodal analysis, Thevenin and Norton equivalents, transient analysis, AC steady state, and other topics that are typical for a first university-level course in circuit analysis. Recently, the CATE learning materials have been formatted to permit direct import into Canvas [6], in the form of practice quizzes and question banks for assessment.

Prior published results [7] suggested that students who use CATE problems for practice have improved scores on traditional in-class exams. This paper focuses on the benefits of using CATE materials for peer learning. For example, using CATE materials may lessen concerns of flawed approaches that may occur when learning from peers, as described by Boud [1]. And, using CATE materials for assessment creates an environment in which students can work together but cannot copy circuit analysis equations from each other. This is because each student can be assigned structurally distinct circuits having different KVL and KCL equations.

This study furthered the development of CATE, using a survey to examine student perceptions of the materials, as well as a comparison with face-to-face peer learning.

Research question and survey design

We pose the following research question -

1. Can the use of CATE materials benefit student learning at a level similar to face-to-face peer learning?

Specifically, students were asked their perceived benefit for each area listed in Table 1. Questions covered each dimension A-F. Students were asked to compare peer learning versus learning with CATE.

Table 1: Dimensions of perceived benefits for both CATE and peer learning.

Letter	Description
A	Helped when considering varied approaches for an analysis
B	Helped clarify my need for additional studying
C	Helped validate my own understanding
D	Helped boost confidence in my abilities
E	Helped discover something misunderstood or unknown to me
F	Helped promote further discussion or questions

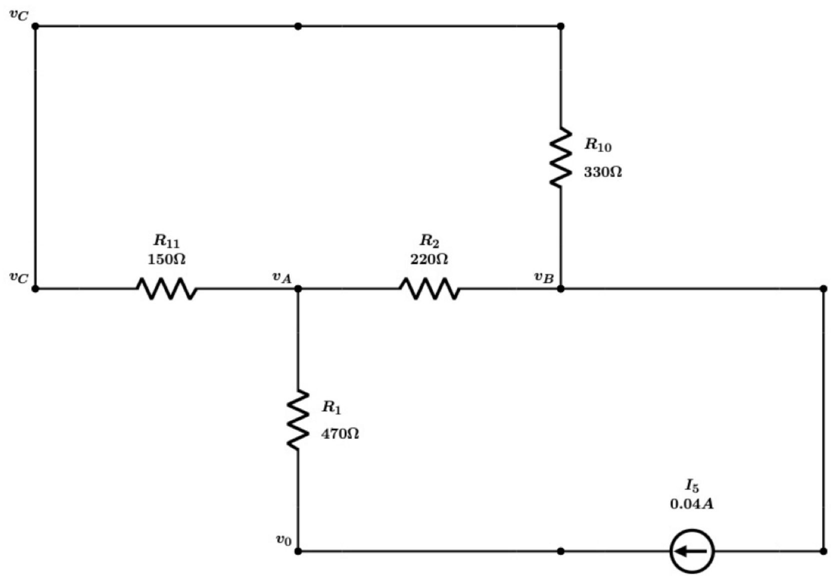
These survey questions were inspired by negative behaviors of overconfident students who often overestimate their abilities and miss opportunities for validation or to discover gaps. Negative behaviors of overconfident students are related to the Dunning-Kruger effect [8][9]. This effect is a cognitive bias where a lack of self-awareness prevents an incompetent person from recognizing their own mistakes. For the survey, the negative behaviors were re-expressed in a positive sense. Note also that some behaviors in the survey also resemble characteristics of a growth mindset [10]. The survey was not intended to measure growth mindset or overcondifence, but the associated positive behaviors were deemed desirable aspects of peer learning.

How might CATE/Canvas benefit peer learning, compared to other systems?

CATE materials are unique due to a combination of features:

1. Randomized circuit generation appropriate to a learning objective and with constraints for difficulty,
2. Detailed step-by-step solutions with explanatory text,
3. Compatibility with Canvas permits large numbers of analysis problems to be incorporated into a course to use for examples, practice and assessment.

One potential use of the CATE/Canvas materials is to refresh old homework problems. Lang [11] describes student groups that pride themselves on having old assessment materials. With CATE, the large number of problems provide a convenient means to refresh assignments. Lang refers to this as “grounded assessment” and is a recommended practice to mitigate cheating [11]. The large number of CATE problems also provide options regarding the approach to assessment. For example, instructors can provide more lower-stakes assessments rather than a single high-stakes version. Lang describes this environment as one that promotes mastery learning, rather than one that focuses on exam performance. This is another recommended practice to mitigate cheating [11]. Reviewing numerous no-stakes practice problems have been shown to improve



Hence, the KCL equations for each node are

$$\begin{cases} KCL_A : I_A^{(R1)} + I_A^{(R2)} + I_A^{(R11)} = 0 \\ KCL_B : I_B^{(R2)} + (I_5) + I_B^{(R10)} = 0 \\ KCL_C : I_C^{(R10)} + I_C^{(R11)} = 0 \end{cases}$$

$$\begin{cases} KCL_A : (v_A)/R_1 + (v_A - v_B)/R_2 + (v_A - v_C)/R_{11} = 0 \\ KCL_B : (v_B - v_A)/R_2 + (I_5) + (v_B - v_C)/R_{10} = 0 \\ KCL_C : (v_C - v_B)/R_{10} + (v_C - v_A)/R_{11} = 0 \end{cases}$$

Introducing coefficients based on component values

$$\begin{cases} KCL_A : (v_A)/470 + (v_A - v_B)/220 + (v_A - v_C)/150 = 0 \\ KCL_B : (v_B - v_A)/220 + (0.04) + (v_B - v_C)/330 = 0 \\ KCL_C : (v_C - v_B)/330 + (v_C - v_A)/150 = 0 \end{cases}$$

Simplifying coefficients using LCM of denominators associated with each KCL equation.

$$\begin{cases} KCL_A : 330.0v_A + 705.0v_A - 705.0v_B + 1034.0v_A - 1034.0v_C = 0 \\ KCL_B : 3.0v_B - 3.0v_A + 26.4 + 2.0v_B - 2.0v_C = 0 \\ KCL_C : 5.0v_C - 5.0v_B + 11.0v_C - 11.0v_A = 0 \end{cases}$$

Expressing in matrix form

$$\begin{bmatrix} 2069.0 & -705.0 & -1034.0 \\ -3.0 & 5.0 & -2.0 \\ -11.0 & -5.0 & 16.0 \end{bmatrix} \begin{bmatrix} v_A \\ v_B \\ v_C \end{bmatrix} = \begin{bmatrix} 0.0 \\ -26.4 \\ 0.0 \end{bmatrix}$$

Solving the matrix equation yields the following numeric values

$$\begin{bmatrix} v_A \\ v_B \\ v_C \end{bmatrix} = \begin{bmatrix} -18.8\,\mathrm{V} \\ -24.83\,\mathrm{V} \\ -20.69\,\mathrm{V} \end{bmatrix}$$

Figure 1: Excerpt of a node voltage analysis. The randomized circuit and equations were generated automatically by CATE. Final numerical results are checked against results from SPICE to ensure correctness.

long-term retention, as described by Brown [12]. It has also been shown to promote retention thanks to the testing effect [11].

The native quizzing engines in Canvas [6] and Moodle [13] support randomized questions. However, these other systems only randomize a single parameter, such as a component value. An instructor-supplied equation then determines the correct answer. This simpler style of randomization results in circuit problems that have the same equations, but for the random parameter. The CATE/Canvas approach is better because it provides structurally distinct circuits that can be assigned to each student. So when collaborating, students have to derive distinct equations for their assigned problem. This is intended to promote a deeper level of engagement, as opposed to students simply copying equations from each other.

Systems such as ZyBooks [14], Mastering [15] and Wiley+ [16] leverage textbooks, and thus are positioned to provide thorough explanations. However, examples can be more limited in a textbook compared to those available with CATE. Also, the explanations within CATE are geared towards solving problems; the focus is less on general principles, as in a textbook. Given these contrasting goals, CATE materials can complement both traditional and electronic textbooks, rather than compete with them, and CATE materials are free.

In contrast to generative AI systems, CATE employs dedicated algorithms to establish circuit equations and solve. Results are then verified using NGspice [17] to ensure that the final numerical results are correct. Also, the total absorbed power of all elements is verified to be zero (allowing for roundoff errors). Thus, CATE materials do not suffer from AI hallucinations. These incorrect and misleading responses can occur when a jumble of source content is improperly combined. As such, hallucinations cannot be tolerated in an educational setting where the goal is to provide formative materials to help develop student abilities. In the early stages of learning students may fail to recognize mistakes in source materials, thus, it is critical to ensure correctness. CATE logic is dedicated to circuit analysis. It does not strive to be general purpose. This limits the functionality for CATE, but it does assure correctness.

Assessment and results

Table 2: T-test results comparing each dimension of perceived benefit in Table 1. Mean values were for the difference in responses of (learning with peers) – (learning with CATE materials). The small positive values for most dimensions indicate that peer learning was a little better than CATE. However, it was not significantly better. This is considered a good result, assuming that peer learning is a best-case situation.

	(A) Approach	(B) Study	(C) Validate	(D) Confidence	(E) Discovery	(F) Discussion
Mean	0.522	-0.217	0.087	0.261	0.261	0.391
Variance	0.897	0.905	0.447	0.565	1.383	1.067
N	23	23	23	23	23	23
p-value two-tail	0.015	0.285	0.539	0.110	0.299	0.083
Significant Difference	None	None	None	None	None	None

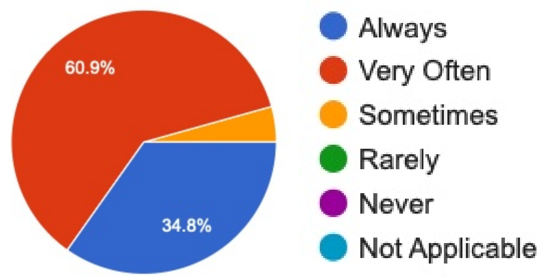


Figure 2: "Approximately 92% reported spending at least 20% of their time studying with peers on a typical week, in the circuits course."

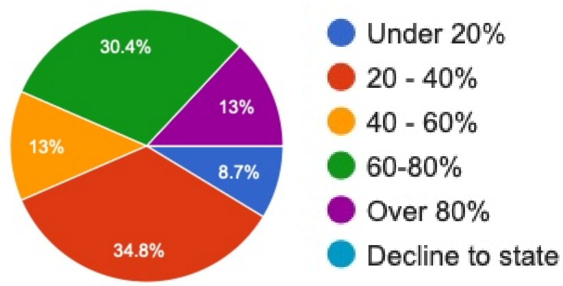


Figure 3: "Over 95% of students found peer learning helpful, either always or very often."

As peer learning was encouraged and not required, a first survey question examined how much time students spent learning with peers. Results indicate that most all students did, albeit to differing levels. See Figure 2. Approximately 92% of students reported spending at least 20% of their time studying with peers on a typical week.

Secondly, did students find peer learning beneficial? As seen in Figure 3, over 95% described peer learning as helpful either always or very often.

As the CATE practice problems were recommended but not required in the course, another preliminary question is whether students used them. Based on usage logs, the number of CATE practice problems accessed by students averaged 79, ranging from 4 to 375. This was associated with a 15-week semester. Accessing a problem consisted of clicking to see a given circuit, at a minimum. Thus, students accessed an average of 5 problems per week.

Based on the above results, it appears that all the students engaged in both face-to-face peer learning and used CATE materials to some degree. To compare students' perception of the benefit of peer learning versus the CATE materials, the Likert scale (Always, Very Often, Sometimes, Rarely, Never) was mapped into the values (+2, +1, 0, -1 -2). A t-test was then used to check for significant differences.

To compare perceptions of peer learning versus CATE materials, the numerical value for CATE was subtracted away from the value for peer learning. A separate t-test was then performed for each dimension in the survey, A-F. See Table 2.

A two-tail p-value was used due to the lack of a priori knowledge regarding whether peer learning or CATE would be ranked higher. As seen in Table 2, none of the p-values fell below an alpha of

0.05. This suggests that there is no significant difference in students' perceived value of peer learning versus the CATE materials, in any of these dimensions. Assuming that learning from another person is a best-base situation, this is considered a good result. Examining the mean differences, most are positive values indicating that face-to-face peer learning was deemed better. However, the benefit was not statistically significant.

Summary and Conclusion

CATE learning materials can supplement a peer learning environment by providing numerous examples and the opportunity for students to verify their abilities. This enhanced environment can provide several benefits that are consistent with recommended best practices. CATE can help refresh assessment materials to mitigate concerns with cheating [11]. It provides a large number of examples to promote long-term retention [12] and promotes retention via the testing effect [11]. And, CATE helps mitigate issues with flawed guidance or approaches when learning with peers [1]. Also, quizzes that are setup with multiple retries involving different circuits approximate competency-based grading [18, 19].

This study has furthered the development process of CATE, indicating that students' perceived benefit of it does not differ significantly from face-to-face peer learning.

Some CATE materials can be accessed directly from `YourLearningCoach.org`. Instructors can email `contact@YourLearningCoach.org` for information on how to access the Canvas Course Export Files.

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