2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #34214

Student Usage of Auto-graded Activities in a Web-based Circuit Analysis Textbook

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Student usage of auto-graded activities in a Circuit Analysis textbook

Abstract

In this paper, we analyze the use of auto-graded circuits analysis problems, called challenge activities, by over 800 students across 8 courses in 4 universities to understand metrics such as: the average completion rate, the average time spent on each activity, and the average number of attempts per problem level. We also identify the percentage of students that struggle, and the percentage of students that gave up. From our analysis we've found the activities around the topics of maximum power transfer, nodal equations, Norton equivalents, and series and parallel resistors to be the hardest due to math requirements and the need to identify series and parallel circuit elements.

Introduction

Engineering courses have increasingly been turning to online resources for textbooks and lab materials. This trend has been especially noticeable during the COVID-19 pandemic, as universities have needed to transition between in-person and online classes. As a result, instructors have progressively been using online, auto-graded problems for homework. Auto-graded homework problems have some benefits over traditional homework problems. Traditional homework problems are typically completed by hand, and can take time for instructors to grade and return to students. In that time, a class has typically moved on to another topic. Auto-graded problems can provide immediate feedback to students to allow them to understand concepts they might be struggling with. Additionally, auto-graded problems may be able to be randomized, allowing students to practice different versions of questions.

We have developed a number of auto-graded problems, called challenge activities, in the context of a web-based, interactive linear circuit analysis textbook. Each challenge activity consists of three to five levels of randomized problems, starting with relatively basic conceptual problems and progressing to more advanced questions. Students must answer each question level correctly in order to move on to the next level. If a question is answered incorrectly, the student is given immediate feedback, and another question of similar difficulty is shown.

This paper provides an analysis of student usage of challenge activities. This paper presents an analysis of the top 4 most difficult challenge activities for 822 students across 8 courses in 4 universities.

Background

Linear circuit analysis courses have increasingly been utilizing circuit simulation software to help students understand and test their knowledge of circuit analysis concepts. However, such software has most often been used for circuit analysis laboratory courses, where students learn to design, test, and build simple and complicated circuits post-lecture. More recently, software tools have been developed to specifically aid students in the learning of circuit analysis concepts. This section describes others' research on developing and implementing interactive tools for learning circuit analysis.

SugarAid is an auto-graded homework system Marepalli et. al designed to prepare students for in-class examinations [1]. Students open up a MATLAB homework data file and run the program to generate timed homework problems. Each problem is displayed with a timer counting down minutes until the answer must be provided. If a student does not complete the exercise in time, the problem vanishes, and students may re-try or skip the problem. Correct answers allow students to move on to another question, while incorrect answers result in a hint or a detailed solution.

Skromme et. al.developed a step-based tutoring system for teaching 15 linear circuit analysis concepts [2][3][4]. For each concept, students are presented with a randomly generated, auto-graded problem that requires answers in the form of numerical inputs, alphanumeric equations, multiple choice answers, sketches of time-dependent waveforms, or circuit diagrams. In a randomized, controlled laboratory-based study, the researchers found the use of the tutorials rustled in a significant learning gain for students when compared to working on conventional textbook problems.

This paper aims to add to the body of research around auto-generated, auto-graded linear circuit analysis problems, specifically ones embedded in the context of a web-based, interactive circuit analysis textbook.

Challenge activity definition

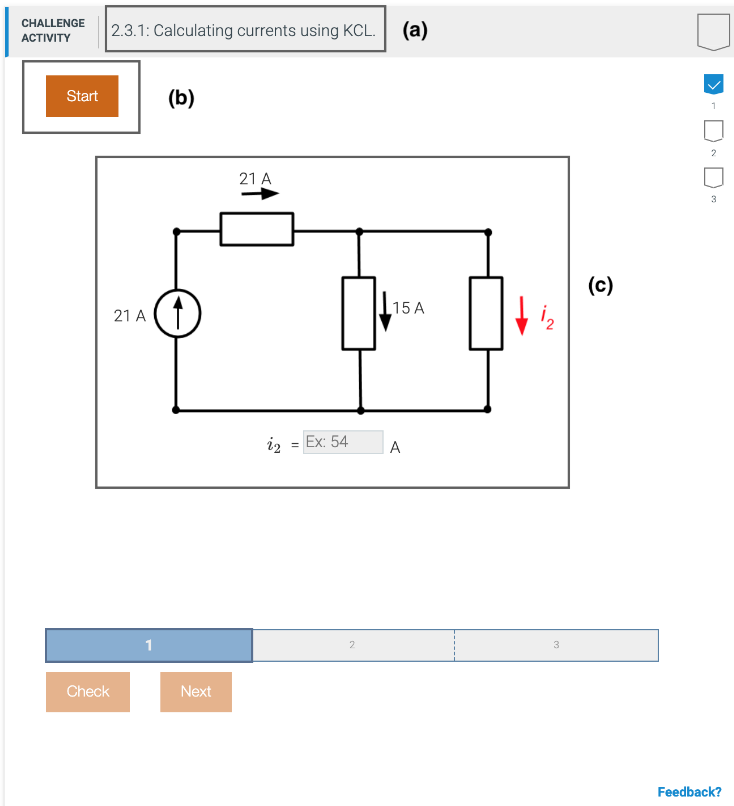
A challenge activity is an auto-graded, auto-generated question set presented at the end of a reading subsection or section. Challenge activities consist of a minimum of 3 question levels, presented in a consistent sequence of increasing difficulty. The difficulty of the level is determined by content experts with knowledge of common student struggles in the given topic. Ex: Level 1 may be a simple "plug-and-chug" of a given equation. Level 2 may then require some manipulation of the same equation, while Level 3 may require some trickier derivations. Within each level, the questions are randomly generated, varying a combination of the numerical data presented, circuit schematics, and the variable students are asked to solve for. Students must successfully answer the question at each level before proceeding to the next higher level. Should the student submit a wrong answer, an explanation for how to solve the problem is shown, and a new randomly-generated problem of equal difficulty is presented. No time limit or restriction on the number of attempts exists for challenge activities.

This method presents a "structured adaptive" approach, scaffolding concepts in an incremental manner to help students progress, and to allow instructors to pinpoint concepts students may struggle with. The randomization of the questions hinders student ability to copy each other, as each student is presented with a unique problem. The immediate feedback provided allows students to immediately see mistakes made, which helps to interrupt the formation of misconceptions.

Challenge activity environment

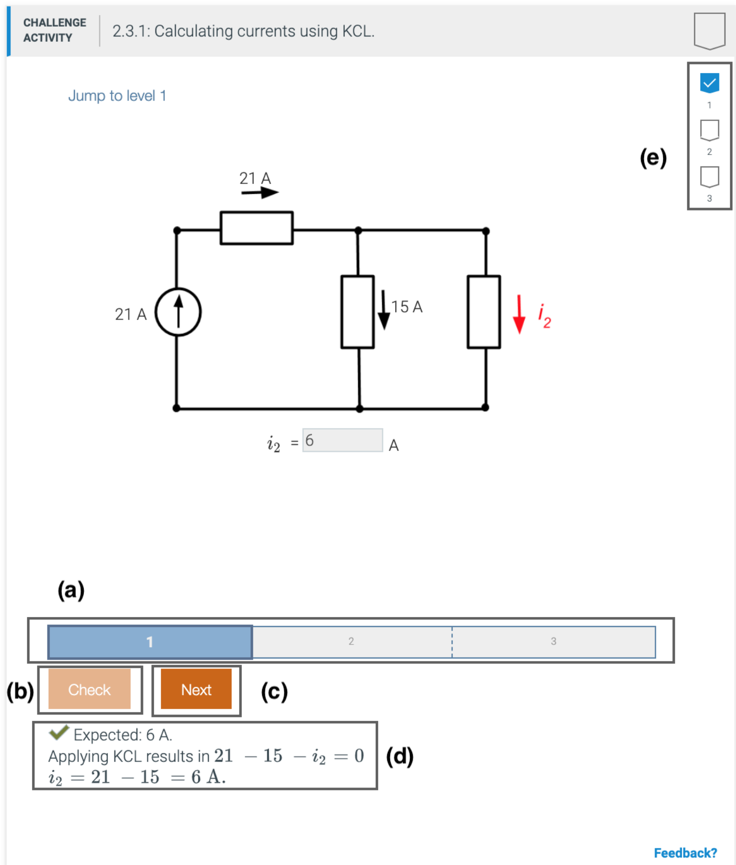
Figure 1 below displays an example of what a student sees when first encountering a challenge activity:
(a). A title describing the challenge at a high level, ex: “Calculating currents using KCL.”
(b). A “Start” button that students can click when ready to start working on the first level of the challenge activity. The start button enables the ability to enter an answer in the input field of the problem.
(c). A problem statement area, displaying the question of the current level and an input field for the student to enter an answer.

Figure 1. Challenge activity "Calculating currents using KCL" labeled with parts: (a). Title, (b). Start button, and (c). Problem statement area.



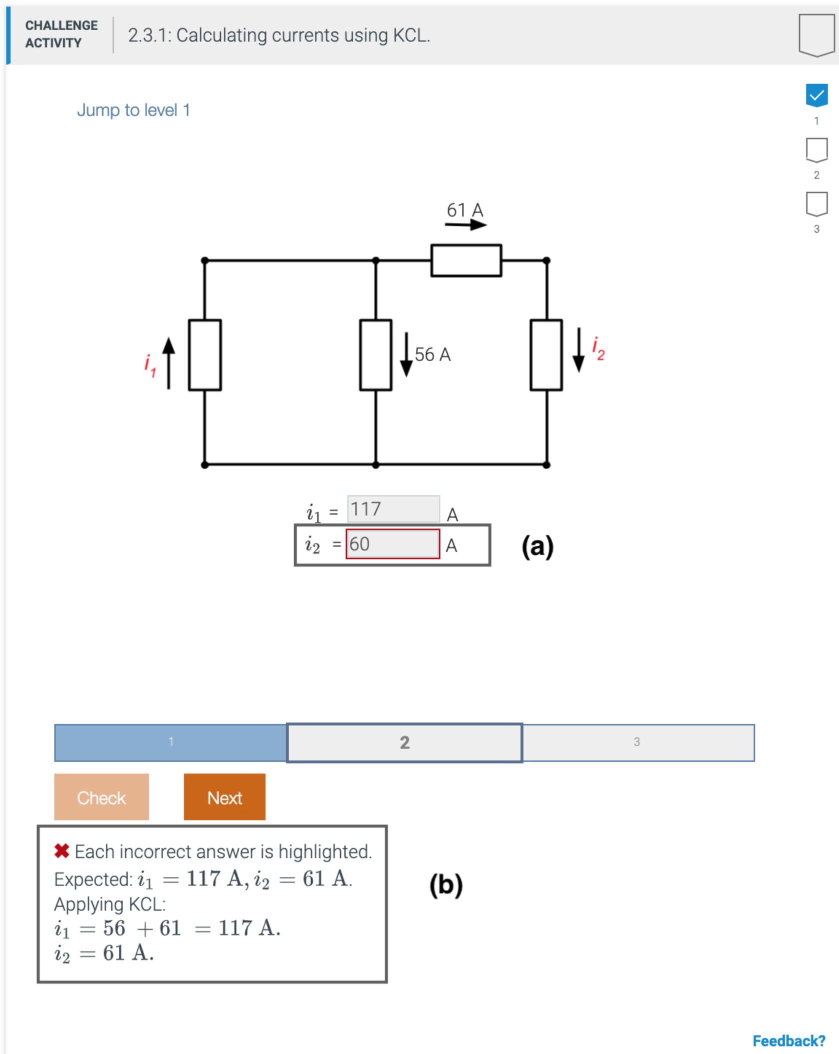
Upon clicking start, students can make an attempt at the problem by entering an answer and pressing the "Check button.". If the answer is correct, an explanation is shown. Two level indicators are filled in to show the completion of the level. A "Next" button appears to prompt the student to move to the next level. Figure 2 demonstrates this example.

Figure 2. A challenge activity with level 1 answered correctly. Highlighted parts: (a). Chevron level indicator, (b). Rectangle level indicator, (c). Check button, (d). Next button, and (e). Explanation.



If a student gets the answer wrong, an X is shown along with an explanation for how to get the correct answer. When a student hits the "Next" button, another problem of a similar difficulty is shown. Figure 3 demonstrates this example.

Figure 3. A challenge activity with level 2 answered incorrectly. Highlighted parts: (a). The incorrect answer, (b). The explanation for obtaining the correct answer.



Methods

Our goal was to better understand student usage of auto-graded circuit analysis problems. The Circuits NI zyBook was created in 2018. Since then, 6668 users across 185 universities have used the zyBook. In July 2019, the Circuits NI zyBook was updated to include a total of 52 challenge activities. To determine which courses and challenge activities to analyze, we used the following criteria:

1. Courses specifically using the latest version of the zyBook during the Fall 2019, Spring 2020, and Fall 2020 semesters or quarters.

2. Courses containing a minimum of 75 students. Having more students in the class gives a better estimate of how well the average student would perform in the course for any given year. Thus, smaller courses tend to have more variability in student performances.
3. Courses where students completed at least 50% of the challenge activities in the zyBook, as this activity completion rate is a good indicator that students were assigned these problems.

These criteria yielded a total of 8 courses across 4 universities with a total of 822 students.

Given these 8 courses, we then determined the challenge activities to analyze by identifying exercises with more than a 70% average completion rate across the courses. This criterion yielded 15 activities, which we narrowed down by comparing the metrics defined in the next section.

Metrics: Definitions

Given the 15 challenge activities, for each level of a challenge activity, and the challenge activity overall, we defined the following metrics:

- Completion rate: The percentage of students who completed the exercise.
- Average number of tries (until correct): Of students who completed the exercise, the sum of each student's number of tries until they answered the question correctly divided by the total number of students.
- Average time spent: Of students who completed the exercise, the sum of each student's time spent in seconds divided by the total number of students.
- Average first time wrong: Of students who worked on the exercise, the sum of the students who answered a given level of the exercise wrong, divided by the total number of students.
- Strugglers rate: The percentage of struggling students. A struggling student is a student who:
    - Spends more than 15 minutes on a single level of the exercise, or
    - Spends more than 5 minutes on a single level, spends more than at least twice as much time as the top 20% students, tries more than 3 times in a single level, and tries at least twice as many times as the top 20% students in a single level.
- Gave up rate: The percentage of students who gave up on that specific exercise. These are students who have some activity recorded in that exercise, but they never successfully completed the activity.

For each of the 15 activities, we then compared these metrics to determine how many times each of those 15 activities appeared within the top 5 of the metric. Ex: How many times the challenge activity "Maximum power transfer" was one of the top 5 activities where students spent the most time (time spent) for each course. From this comparison, 4 common challenge activities were identified.

In this paper, we present analyses of the top 4 hardest challenge activities common across all 8 courses. Table 1 summarizes the universities, courses, and challenge activity completion rates. Each unique university is designated with a letter, followed by the term when the course took place: ‘S’ for spring and ‘F’ for fall.

Table 1. A summary of the number of students and completion rates for four challenge activities across six courses. For each course, the university is designated by a letter. followed by the course term: ‘S’ for spring and ‘F’ for fall.

	A S2020	A F2020	B F2019	B S2020	B F2020	C S2020	D S2020	D F2020
Number of students	78	82	122	103	102	118	113	104
Maximum power transfer (%)	75	76	100	92	90	100	0	30
Norton equivalents (%)	77	81	100	95	91	100	9	32
Nodal equations (%)	87	84	100	98	90	100	7	45
Equivalent resistances for combinations of series and parallel resistors (%)	87	79	100	96	93	100	16	52

Data and Analysis

This section provides an analysis of the top 4 hardest challenge activities for students in the 8 courses, from the most challenging to least challenging. For each challenge activity, we provide a description of the challenge activity, a summary of the metrics across all 8 courses, a breakdown of the hardest level metrics by each course, and our thoughts on why specific activity levels were difficult.

Maximum Power Transfer

The challenge activity “Maximum power transfer” consists of four levels and is designed to help students learn to calculate the load resistance, Thevenin voltage, and power load in a given circuit. Level 1 focuses on finding the load resistance. Level 2 focuses on finding the Thevenin voltage. Level 3 focuses on finding the power load. Finally, level four focuses on finding all three values in a single problem. Figure 4 displays the “Maximum power transfer” challenge activity.

Figure 4. Levels 1-4 of the challenge activity “Maximum power transfer.”

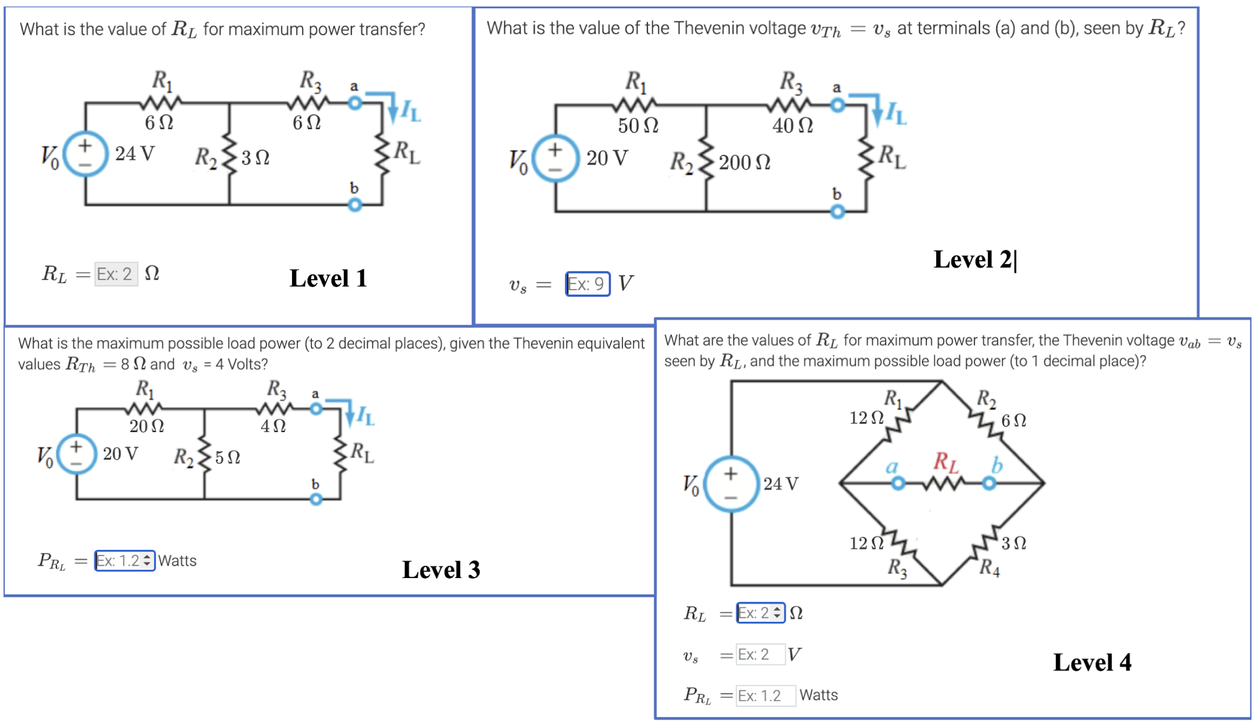


Table 2 displays the number of times “Maximum power transfer” was in the top 5 challenge activities for each metric across all 8 courses. Table 3 displays the same comparison for each of the levels of the challenge activity.

Table 2. Number of times challenge activity “Maximum power transfer” was in the top 5 challenge activities for each metric across all 8 courses.

Metric	Number of courses where metric was in top 5
First time wrong rate	7
Tries until correct	5
Time spent (s)	7
Strugglers rate	6
Gave up rate	7

Table 3. Number of times each level of “Maximum power transfer” was in the top 5 challenge activities for each metric across all 8 courses. The highlighted row indicates the hardest level.

Level	**First time wrong rate**	**Tries until correct**	**Time spent (s)**	**Strugglers rate**	**Gave up rate**
1	2	2	0	5	0
2	4	1	0	5	0
3	4	3	1	5	1
4	7	5	7	6	7

Level 4 was the most challenging, having the highest first time wrong rate, the most number of tries until correct, the longest time spent, the highest strugglers rate, and the highest rate for students giving up across all 8 courses. Table 4 displays the metrics across all 8 courses. On average, 77% of students got the answer wrong on the first attempt, made an average of 3 attempts before obtaining the correct answer, and spent an average of 7 minutes on the problem. Across the courses, 29% of students struggled on this level, with 6% giving up on the level.

Table 4. Metrics for level 4 of "Maximum power transfer" across all 8 courses.

	First time wrong rate	Tries until correct	Time spent (s)	Strugglers rate	Gave up rate
A S2020	92%	3.73	546.92	48%	4%
A F2020	97%	3.51	467.4	35%	13%
B F2019	96%	4.22	453.78	40%	9%
B S2020	86%	3.32	419.82	26%	1%
B F2020	92%	3.76	449.31	31%	1%
C S2020	60%	2.69	321.31	16%	3%
D S2020	No activity	No activity	No activity	No activity	No activity
D F2020	96%	2.63	353.33	9%	11%

One of the reasons we believe students struggled with this level was the failure to recognize which resistors were truly in parallel, and which were in series. In previous levels, a much simpler circuit schematic was presented. Level 4 presents a bridge, which may be a trickier schematic for students to analyze. Additionally, previous levels requested only one variable as an input. Level 4 requires 3 variables, so a higher chance exists for students to get the entire problem incorrect by getting one variable wrong.

Norton Equivalents

The challenge activity "Norton equivalents" consists of four levels and is designed to help students learn to calculate Norton equivalents for circuits by calculating the Norton equivalent resistance and Norton current for different circuits. Level 1 focuses on finding the Norton equivalent resistance for a circuit containing two resistors. Level 2 focuses on finding the Norton current for the same circuit. Level 3 focuses on finding the Norton resistance for a circuit containing 3 resistors. Finally, level 4 focuses on finding the Norton current for the same circuit. Figure 5 displays the "Norton equivalents" challenge activity.

Figure 5. Levels 1-4 of the challenge activity “Norton equivalents.”

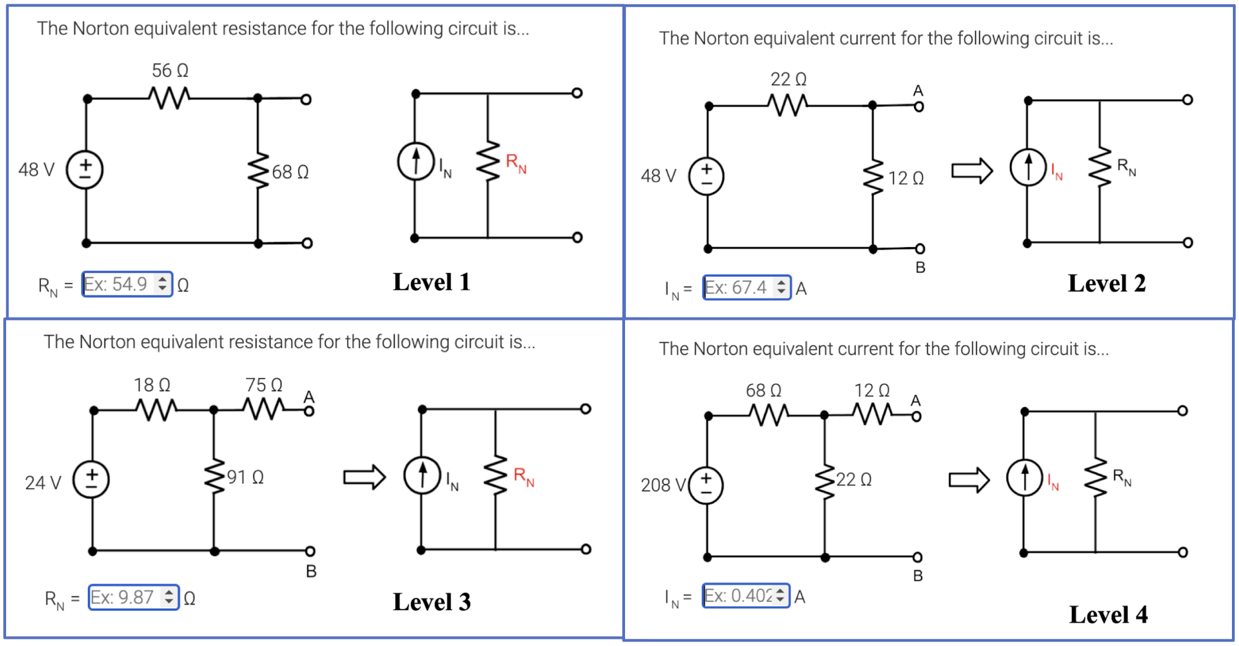


Table 5 displays the number of times “Norton equivalents” was in the top 5 challenge activities for each metric across all 8 courses. Table 6 displays the same comparison for each of the levels of the challenge activity.

Table 5. Number of times challenge “Norton equivalents” was in the top 5 challenge activities for each metric across all 8 courses.

Metric	Number of courses where metric was in the top 5
First time wrong rate	6
Tries until correct	4
Time spent (s)	8
Strugglers rate	3
Gave up rate	4

Table 6. Number of times each level of "Norton equivalents" was in the top 5 challenge activities for each metric across all 8 courses. The highlighted row indicates the hardest level.

Level	First time wrong rate	Tries until correct	Time spent (s)	Strugglers rate	Gave up rate
1	0	0	0	3	0
2	3	0	0	2	0
3	0	0	0	2	0
4	3	4	8	2	4

Level 4 was the most challenging, having the highest first time wrong rate, the most number of tries until correct, the longest time spent, and the highest rate for students giving up across all 8 courses. Table 7 displays the metrics across all 8 courses. On average, 47% of students got the answer wrong on the first attempt, made an average of 3 attempts before obtaining the correct answer, and spent an average of 5 minutes on the problem. Across the courses, 17% of students struggled on this level, with 4.5% giving up on the level.

Table 7. Metrics for level 4 of "Norton equivalents" across all 8 courses.

	First time wrong	Tries until correct	Time spent (s)	Strugglers rate	Gave up rate
A S2020	0%	1	285.65	0%	0.02%
A F2020	93%	5.69	342.57	34%	12%
B F2019	90%	4.06	352.36	34%	5%
B S2020	0%	1	284.23	0%	0%
B F2020	93%	5.19	320.53	31%	2%
C S2020	0%	1	194.08	0%	0%
D S2020	0%	1	241.12	0%	0%
D F2020	97%	4.09	309.79	34%	15%

One reason we believe students might struggle on level 4 is due to the need to calculate a voltage, and then use Ohm's Law to find the Norton current. In level 3, students get familiar with calculating the equivalent resistance. Level 4 requires not only this calculation, but also calculating the voltage across the equivalent resistance. Students must then use this voltage and Ohm's Law to calculate the current through the other resistor.

Additionally, students might be confused as to which resistors are in series once the voltage source is shorted. This would result in the wrong equivalent resistance to be calculated, making the calculated current incorrect.

Nodal Equations

The purpose of the challenge activity "Nodal equations" is to practice the voltage-node method for a variety of circuit configurations, starting from simpler circuits with fewer equations and growing in difficulty level. Prior to this challenge activity, the solution procedure was introduced, and an example with two independent sources was solved in detail. The students have also practiced the method in a series of questions related to a simple circuit with one voltage source.

In levels 1 to 3, the students are asked to identify the equations for different currents (level 1 and level 2) and come up with the Kirchoff's Current Law equation for a specific node in a two source circuit (level 3). No mathematical computations are required for any of these levels. Level 4 then asks students to calculate the numerical value of the node voltage and current. Figure 6 below shows the challenge activity "Nodal equations."

Figure 6. Levels 1-3 of the challenge activity "Nodal equations."

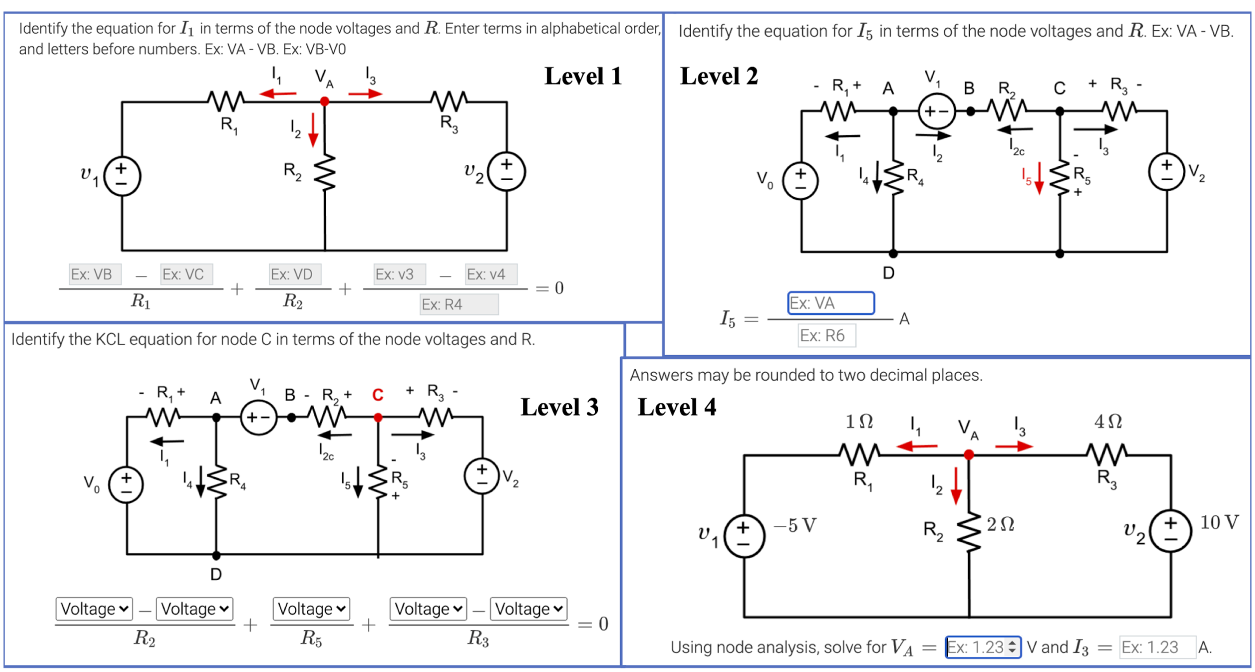


Table 8 displays the number of times “Nodal equations” was in the top 5 challenge activities for each metric across all 8 courses. Table 9 displays the same comparison for each of the levels of the challenge activity.

Table 8. Number of times challenge “Nodal equations” was in the top 5 challenge activities for each metric across all 8 courses.

Metric	Number of courses where metric was in the top 5
First time wrong rate	0
Tries until correct	3
Time spent (s)	6
Strugglers rate	2
Gave up rate	5

Table 9. Number of times each level of “Nodal equations” was in the top 5 challenge activities for each metric across all 8 courses. The highlighted cells indicate the highest value for each metric.

Level	**First time wrong rate**	**Tries until correct**	**Time spent (s)**	**Strugglers rate**	**Gave up rate**
1	0	0	0	1	1
2	0	0	0	1	0
3	0	0	0	0	3
4	0	3	5	0	1

Level 4 was the most challenging, having the most number of tries until correct, the longest time spent, and the highest rate for students giving up across all 8 courses. Table 10 displays the metrics across all 8 courses.

The aggregated data on time spent on various circuit problems reveals an average time between 3 to 5 minutes for solving a typical circuit problem, including all the required calculations.

Our data analysis from 8 courses shows that students on average spent between 3.6 and 8.1 minutes on the level 4 of this challenge activity. Furthermore, in 3 courses, the majority of students tried this level at least twice to get the right answer. Also, the number of struggling students is comparable to other levels of this challenge activity.

Table 10. Metrics for level 4 of "Nodal equations" across all 8 courses.

	First time wrong rate	Tries until correct	Time spent (s)	Strugglers rate	Gave up rate
A S2020	0%	1	216.84	2%	0%
B S2020	0%	1	236.16	0%	0%
C S2020	0%	1	231.15	2%	2%
D S2020	0%	1	319.14	0%	0%
B F2019	77%	3.01	471.36	28%	2%
A F2020	86%	3.97	448.19	35%	0.1%
B F2020	67%	2.78	443.73	29%	2%
D F2020	85%	2.76	483.26	28%	7%

To be successful in level 4, students should be comfortable using nodal analysis. Two quantities are calculated for this level: one voltage value and one current value. The calculation of current is dependent on the voltage. Therefore, the voltage and current calculation cannot be done separately. One current equation has already been derived in level 1. Therefore, students should be familiar with the current equation at level 4.

What seems to be the point of confusion at this level is the replacement of numbers for voltage and resistors, and the calculation of voltage value. One source of error may be the use of two sources and the need to subtract voltages, instead of just using one voltage value in the equations to find the correct voltage or current value. Although students have already seen the nodal equations and used them in previous levels, this level is their first attempt to solve the problem and find actual numerical values for voltage and current.

Another source of error may be the requirement for rounding the answer to two decimal places. Academically, students are expected to have mastered rounding up the numbers and the concept of significant figures. However, it is observed that students still struggle with math at this level.

Equivalent resistances for combinations of series and parallel resistors

In this challenge activity, equivalent resistances for various combinations of series and parallel resistors are calculated in 5 levels. All 5 levels include both series and parallel resistors. The overall complexity of circuit and number of resistors increase with each level. Figure 7 demonstrates the levels of the "Equivalent resistances for combinations of series and parallel resistors" challenge activity.

Figure 7. Levels 1-5 of the challenge activity "Equivalent resistances for combinations of series and parallel resistors."

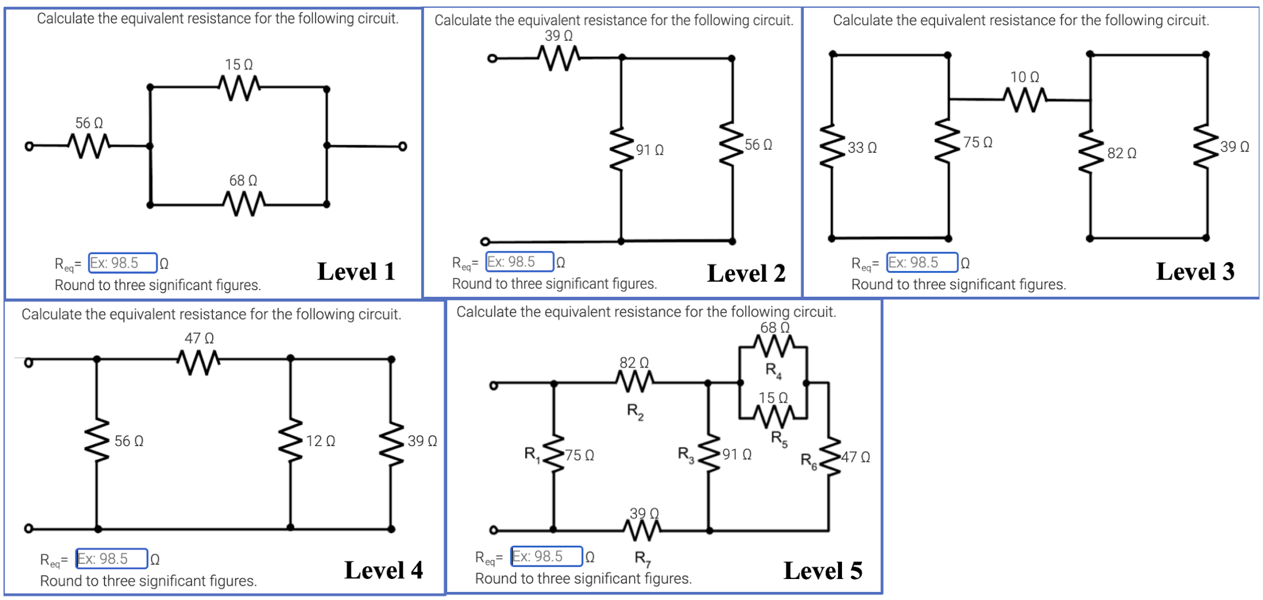


Table 11 displays the number of times "Equivalent resistances for combinations of series and parallel resistors" was in the top 5 challenge activities for each metric across all 8 courses. Table 12 displays the same comparison for each of the levels of the challenge activity.

Table 11. Number of times challenge activity "Equivalent resistances for combinations of series and parallel resistors" was in the top 5 challenge activities for each metric across all 8 courses.

Metric	Number of courses where metric was in the top 5
First time wrong rate	0
Tries until correct	0
Time spent (s)	0
% strugglers	1
Gave up %	2

Table 12. Number of times each level of "Equivalent resistances for combinations of series and parallel resistors" was in the top 5 challenge activities for each metric across all 8 courses.

Level	**First time wrong rate**	**Tries until correct**	**Time spent (s)**	**Strugglers rate**	**Gave up rate**
1	0	0	0	1	0
2	0	0	0	1	0
3	0	0	0	0	1
4	0	0	0	0	0
5	0	0	0	0	1

This challenge activity was easier compared to others, and no particular level stands out to be particularly challenging. Two courses had some students struggle with levels 1 and 2, and two courses had students give up for levels 3 and 5. Level 5 was the most complicated, and did have the highest give up rate compared to level 3. Table 13 displays the metrics across all 8 courses for level 5.

On average, 19% of students got the answer wrong on the first attempt, made an average of 2 attempts before obtaining the correct answer, and spent an average of 3.5 minutes on the problem. Across the courses, 6% of students struggled on this level, with 1% giving up on the level.

Table 13. Metrics for level 5 of “Equivalent resistances for combinations of series and parallel resistors” across all 8 courses.

	First time wrong rate	Tries until correct	Time spent (s)	Strugglers rate	Gave up rate
A S2020	0%	1	217.41	0%	0%
A F2020	64%	5.53	316.95	17%	5%
B F2019	40%	1.62	221.59	9%	0%
B S2020	0%	1	201.25	0%	0%
B F2020	53%	4.53	253.35	14%	0%
C S2020	0%	1	125.33	0%	0%
D S2020	0%	1	153.55	0%	5%
D F2020	63%	1.87	276.79	9%	12%

Level 1 is the first time where students practice more complicated resistor combinations after practicing with some simpler resistor combinations. One common mistake in this type of problem occurs while identifying the parallel and series elements. Other errors may occur during calculations such as errors in arithmetics like multiplication and division.

The 5 levels of this challenge activity provide good practice for determining the resistor combinations. However, as shown in Figure 7, the series or parallel combination of resistors in all 5 levels are visually distinguishable. In later sections such as Thevenin and Norton equivalent circuits, students will encounter more complicated circuits where visual identification of element configuration may not be feasible. Due to the nature of the problem, adding a short circuit or open circuit can change the circuit configuration drastically. Therefore, students should have built a proper foundation for solving such problems in the earlier sections.

Discussion

Comparing the results across all 4 hardest challenge activities, math appears to be a potential problem for students in the course. Students have shown to be able to successfully set up necessary equations (ex: levels 1-3 of “Maximum power transfer”, “Nodal equations”, and “Norton equivalents”), but then fail to calculate answers when presented with circuit values.

Additionally, students may struggle with identifying series and parallel circuit components, both of which are required to successfully complete the “Maximum power transfer” and “Norton equivalents” challenge activities. As a result, we believed we might see similar struggle patterns for the “Equivalent resistances for combinations of series and parallel resistors” challenge activities. However, we found that activity to be the easiest, possibly due to the fact that the components circuit schematics presented are easy to visually identify as in series or parallel.

Future Work and Conclusion

This paper analyzed the use of randomized, structured, and auto-graded Circuits activities by over 800 students across 8 courses. The metrics used to analyze the difficulty of each activity were the average completion rate, the average time spent on each activity, the average number of attempts per problem level, the average tries until an answer was correct, the strugglers rate and the rate of students who gave up on these activities. We analyzed the hardest of those activities, and determined the top 4 most challenging problems around the topics of maximum power transfer, Norton equivalents, nodal equations, and series and parallel resistors.

Given the foundational nature of understanding series and parallel electrical components, future work includes increasing the number of series and parallel challenge activity problems to see if any positive effects occur for increasing the completion rates for problems requiring such knowledge. These levels would include more visually subtle, “trickier” combinations of resistors. One idea would be to find voltage and current at a certain port or node of the circuit in order to be able to identify the equivalent resistance at that port. The practice of obtaining resistance from a specific view of the circuit at earlier sections of the course can lead to lower error rates in more advanced topics, and can help students to focus on the more advanced topic rather than struggling with being lost in identifying a series or parallel combination.

References

[1] Marepalli, P., Magana, A., Taleyarkhan, M. R., Sambamurthy, N., & Clark, J. V. (2010, December). SugarAid 0.2: An Online Learning Tool for STEM. In 2010 International Conference on Computational Intelligence and Software Engineering (pp. 1-6). IEEE.
[2] Skromme, Brian J., et al. "Interactive tutorial system for linear circuit analysis: Impact on learning and novel tutorials." Educational Psychology 2004 (1998): 2010.
[3] Skromme, B. J., Rayes, P. J., Whitlatch, C. D., Wang, Q., Barrus, A., Quick, J. M., ... & Frank, T. S. (2013, October). Computer-aided instruction for introductory linear circuit analysis. In 2013 IEEE Frontiers in Education Conference (FIE) (pp. 314-319). IEEE.
[4] Whitlatch, C. D., Wang, Q., & Skromme, B. (2012). Automated problem and solution generation software for computer-aided instruction in elementary linear circuit analysis. In 119th ASEE annual conference and exposition. American Society for Engineering Education.