CIRCUIT TUTOR EVALUATION REPORT 2022: YEAR FOUR

EVALUATION FINDINGS AND RECOMMENDATIONS

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INTRODUCTION

Program Overview

Researchers at Arizona State University (ASU) led by Principal Investigator Brian Skromme in the School of Electrical, Computer, and Energy Engineering, continued piloting the effectiveness of a step-based tutoring system for an engineering course: Introduction to Linear Circuit Analysis. The work is in collaboration with three other diverse universities: Morgan State University (MSU), Florida A&M University (FAMU), and the University of Texas at El Paso (UTEP) with co-Principal Investigators DeAnna Bailey, Petru Andre, and Miguel Velez-Reyes.

The targeted engineering courses are considered gate-way courses as they are widely taught and serve as required courses in many engineering majors. The tutoring system, Circuit Tutor (CT), is being used in conjunction with a typically taught class as a tool to help with homework and studying for exams. Researchers are examining its effectiveness in increasing student competencies and knowledge of circuitry.

The current project is designed to build on previous success and is also designed to answer research questions related to the tutoring system's instructional effectiveness based on analyses of student progress, feedback, and subsequent performance. The system's effectiveness is also examined comparatively using other products such as WileyPlus, Pearson's Mastering Engineering software, and traditional classroom textbooks.

During fall 2021 and spring 2022, all four of the participating universities in addition to several other higher education institutions provided over 1400 students with CT as an instructional support in their electrical engineering courses.

Evaluation Methods

The external program evaluation examined the outcomes of the fall 2021 and spring 2022 courses. For the fourth year of the project, the evaluation focused on implementation, usability, and satisfaction across the four campuses. A mixed methods approach was utilized through the combination of student and instructor surveys and document review. The survey captured both quantitative and qualitative data using Likert scale items and open-ended questions. Document review used a centralized course monitoring system (https://www.circuittutor.com/web/) which allowed for a review of the course names by campus, the number of students enrolled, and their grades by assignment. Students and instructors from all participating campuses were invited to complete a semester-end survey on their satisfaction with the Circuit Tutor system and their perceptions of its use and viability.

The current report is guided by, and organized around, the following evaluation questions:

1. To what extent was Circuit Tutor implemented effectively across the partnering universities?
2. How did students perceive the utility of Circuit Tutor in supporting their course learning?
3. How did instructors perceive Circuit Tutor to impact their teaching experiences?
4. How did instructors perceive their students to experience Circuit Tutor in their course learning?
5. To what extent were students satisfied with Circuit Tutor?

FINDINGS

1. TO WHAT EXTENT WAS CIRCUIT TUTOR IMPLEMENTED EFFECTIVELY ACROSS THE PARTNERING UNIVERSITIES?

Fall 2021. There were 15 distinct classes with 15 professors teaching Circuits I across five institutions that incorporated CT into coursework. As show in the table below, 11 courses at Arizona State University used CT with 618 enrolled students. Other institutions included Dalhousie University, Florida A & M, Morgan State University and University of Texas at El Paso with 108 enrolled students. Together, 726 students enrolled in an engineering course across these institutions engaged with CT in the fall of 2021.

Fall 2021 Courses	Instructor	Location	Number
EEE 202 Circuits I	DV	Arizona State University	76
EEE 202 Circuits I	MT	Arizona State University	51
EEE 202 Circuits I	SC	Arizona State University	103
EEE 202 Circuits I	BS	Arizona State University	47
EEE 202 Circuits I	HY	Arizona State University	42
EEE 202 Circuits I	JBC	Arizona State University	55
EEE 202 Circuits I	ZF	Arizona State University	49
EEE 202 Circuits I	DM	Arizona State University	26
EEE 202 Circuits I	AM	Arizona State University	48
EEE 202 Circuits I	MR	Arizona State University	74
EEE 202 Circuits I	MW	Arizona State University	47
ENGN 3000	AM	Dalhousie University	9
EEL 3111	PA	Florida A & M University/Florida State University	32
EEGR 202	DB	Morgan State University	32
EE2350 Circuits I	HEC	University of Texas at El Paso	35
TOTAL			**726**

Spring 2022. There were 15 classes across five institutions that utilized CT in their Circuits I course. For this semester, three professors taught multiple sections of classes meaning there were 11 professors using CT platform. As shown on the table below, there were 540 students at Arizona State University's 10 courses, 138 across two course sections at Florida A & M University/Florida State University, 19 students at Glendale Community College in Arizona, 16 at Morgan State University, and 29 at University of Texas at El Paso. The overall total number of students engaged in spring 2022 was 742.

Spring 2022 Courses	Instructor	Location	Number
EEE 202 Circuits I	AE	Arizona State University	80
EEE 202 Circuits I	AM	Arizona State University	52
EEE 202 Circuits I	AM	Arizona State University	51
EEE 202 Circuits I	SC	Arizona State University	53
EEE 202 Circuits I	SC	Arizona State University	51
EEE 202 Circuits I	SC	Arizona State University	57

EEE 202 Circuits I	CW	Arizona State University	49
EEE 202 Circuits I	MW	Arizona State University	49
EEE 202 Circuits I	MW	Arizona State University	49
EEE 202 Circuits I	GF	Arizona State University	49
EEL 3003	JH	Florida A & M University/Florida State University	121
EEL 3111	PA	Florida A & M University/Florida State University	17
EEE 202	TF	Glendale Community College	19
EEGR 202	DB	Morgan State University	16
EE2350 Circuits I	HEC	University of Texas at El Paso	29
TOTAL			**742**

The list of tutorials utilizing CT during fall 2021 and spring 2022 included the following 24 topics:

- Series/Parallel Tutorial
- DC Single Node-Pair/ Single Loop
- Series/Parallel with Terminals
- Resistor Simplification
- DC Node Equations
- DC Node Solutions
- DC Mesh Equations
- DC Mesh Solutions
- DC Superposition
- DC Source Transformations
- DC Thévenin/Norton Equivalent Circuits
- L/C Waveforms
- L/C Simplification
- First-Order Transients
- Second-Order Transients
- Impedance Simplification
- AC Node Equations
- AC Node Solutions
- AC Mesh Equations
- AC Mesh Solutions
- AC Analysis
- Bode Plots
- Laplace Transforms
- Inverse Laplace Transforms

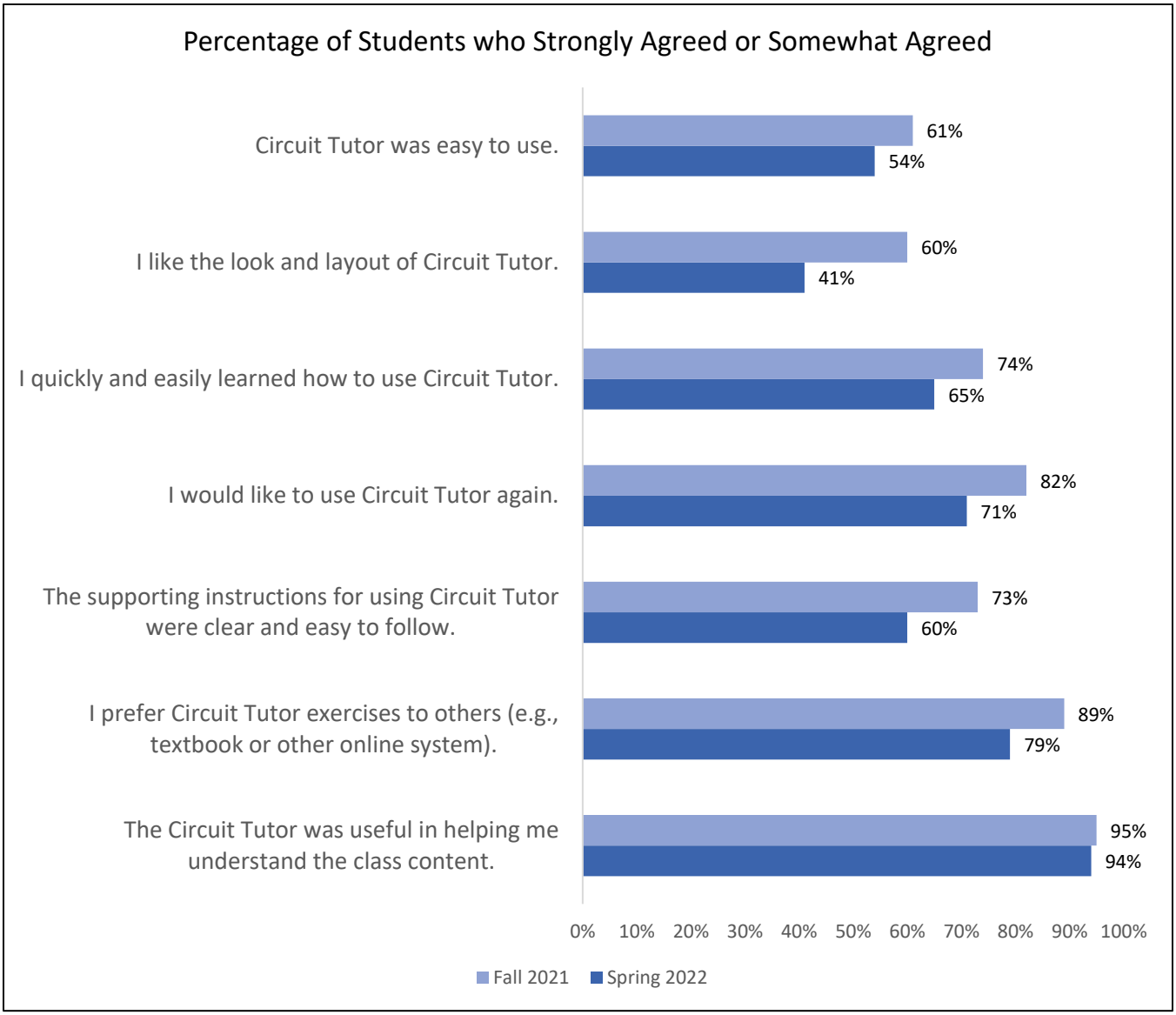
2. HOW DID STUDENTS PERCEIVE THE UTILITY OF CIRCUIT TUTOR IN SUPPORTING THEIR COURSE LEARNING?

Surveys were sent to students at the end of the fall 2021 and spring 2022 semesters at all the participating campuses. The survey response rates are included in the table below. The students were asked about their perceptions of the utilization of CT and their satisfaction with CT across both semesters. All the survey data from both semesters is presented below.

	Fall 2021	Spring 2022
Arizona State University	43% (109/255)	56% (140/251)
Florida A & M University	72% (23/32)	76% (13/17)
Morgan State University	91% (21/23)	0% (0/16)
University of Texas El Paso	72% (23/32)	66% (19/29)

Note. The total numbers of students in the table above are based on the class roster lists sent to CREST by the FAMU, MSU, and UTEP instructors and may vary slightly from the enrollment tables above based on Circuit Tutor course numbers.

Overall, students had very favorable experiences using CT across the fall 2021 and spring 2022 semesters. As shown in the figure below, the highest percentages of students across both semesters somewhat agreed or strongly agreed that 1) Circuit Tutor was useful in helping them understand the class content (fall 2021: 95%; spring 2022: 94%), 2) they preferred CT exercises to others (fall 2021: 89%; spring 2022: 79%), and 3) supporting instructions for using CT were clear and easy to follow (fall 2021: 73%; spring 2022: 60%), and 4) would like to use CT again (fall 2021: 82%; spring 2022: 71%).



Note. The percentages represent those students who strongly agreed or somewhat agreed

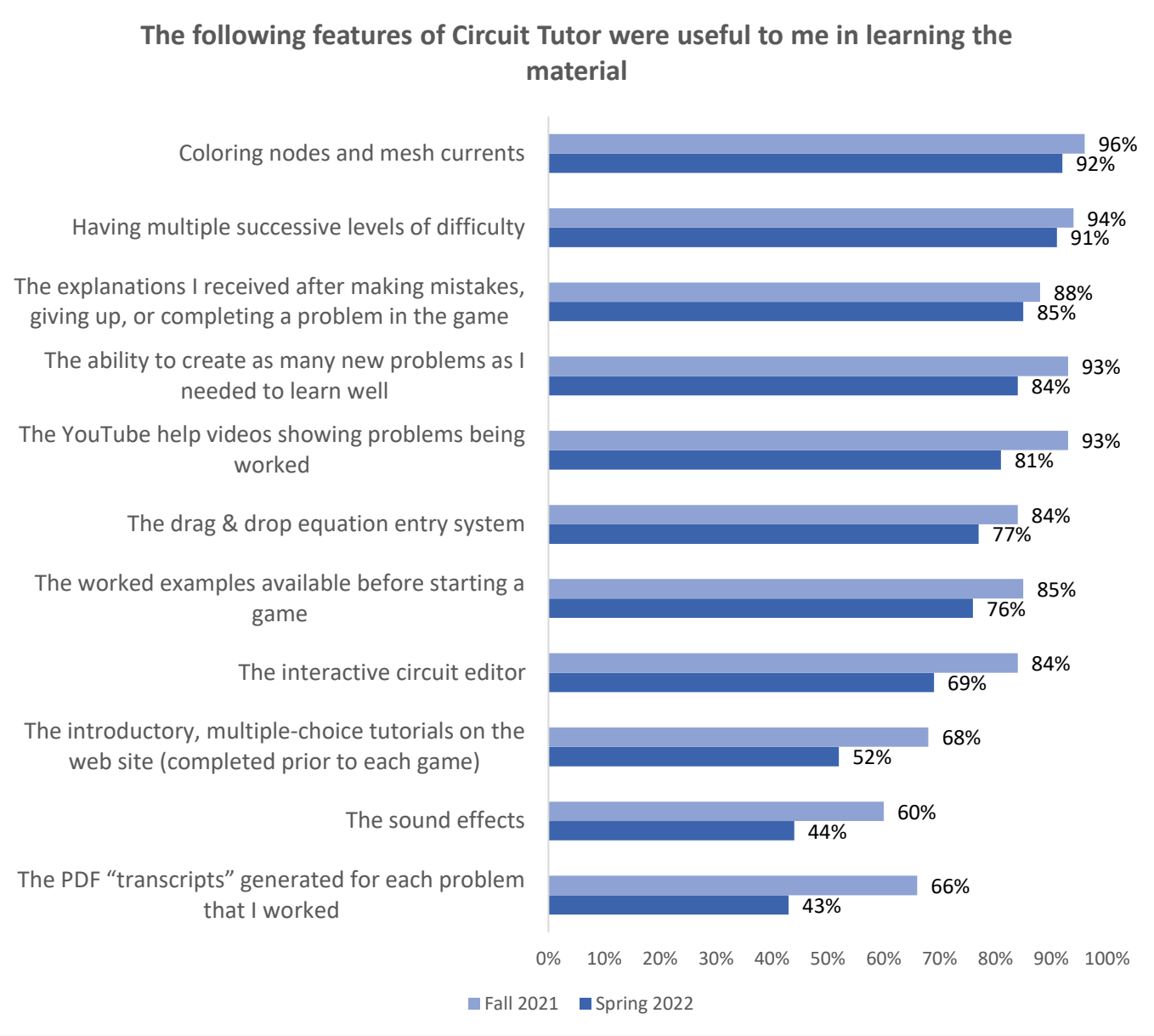
As shown in the table below, there was slight variation in student perceptions of the utility of CT across universities. Additionally, the student perceptions were more favorable in the fall 2021 semester compared to the spring 2022 semester. In the fall 2021 semester, the most favorable perceptions of CT were in students at ASU (79%), FAMU (78%), and UTEP (78%), whereas in the spring 2022 semester, the most favorable perceptions were among students at ASU (70%) and UTEP (53%). It and MSU (64%). It is important to be mindful of the sample sizes for each of the semesters presented below when observing the percentages.

Survey Items	ASU		FAMU		UTEP		MSU	
	F21 N=109	S22 N=141	F21 N=23	S21 N=17	F20 N=19	S21 N=19	F21 N=20	S22[1] N=0
1. The Circuit Tutor was useful in helping me understand the class content.	97%	97%	100%	72%	95%	89%	80%	N/A
2. I would like to use Circuit Tutor again.	83%	75%	95%	50%	95%	58%	68%	N/A
3. I prefer Circuit Tutor exercises to others (e.g., textbook or other online system).	92%	84%	92%	65%	84%	58%	70%	N/A
4. I quickly and easily learned how to use Circuit Tutor.	77%	67%	74%	57%	73%	53%	53%	N/A
5. The supporting instructions for using Circuit Tutor were clear and easy to follow.	77%	63%	74%	35%	74%	47%	48%	N/A
6. Circuit Tutor was easy to use.	65%	58%	60%	43%	79%	31%	48%	N/A
7. I like the look and layout of Circuit Tutor.	62%	44%	50%	21%	63%	33%	24%	N/A
AVERAGE % who “agreed somewhat” or “agreed strongly”	**79%**	**70%**	**78%**	**49%**	**78%**	**53%**	**61%**	**N/A**

Note. The percentages represent those students who reported “somewhat agree” or “strongly agree.”

Students were also asked about the extent to which various features of CT were useful to their learning of the material. As shown below, the most useful components reported by students were coloring nodes and mesh currents (fall 2021: 96%; spring 2022: 92%), having multiple successive levels of difficulty (fall 2021: 94%; spring 2022: 91%).

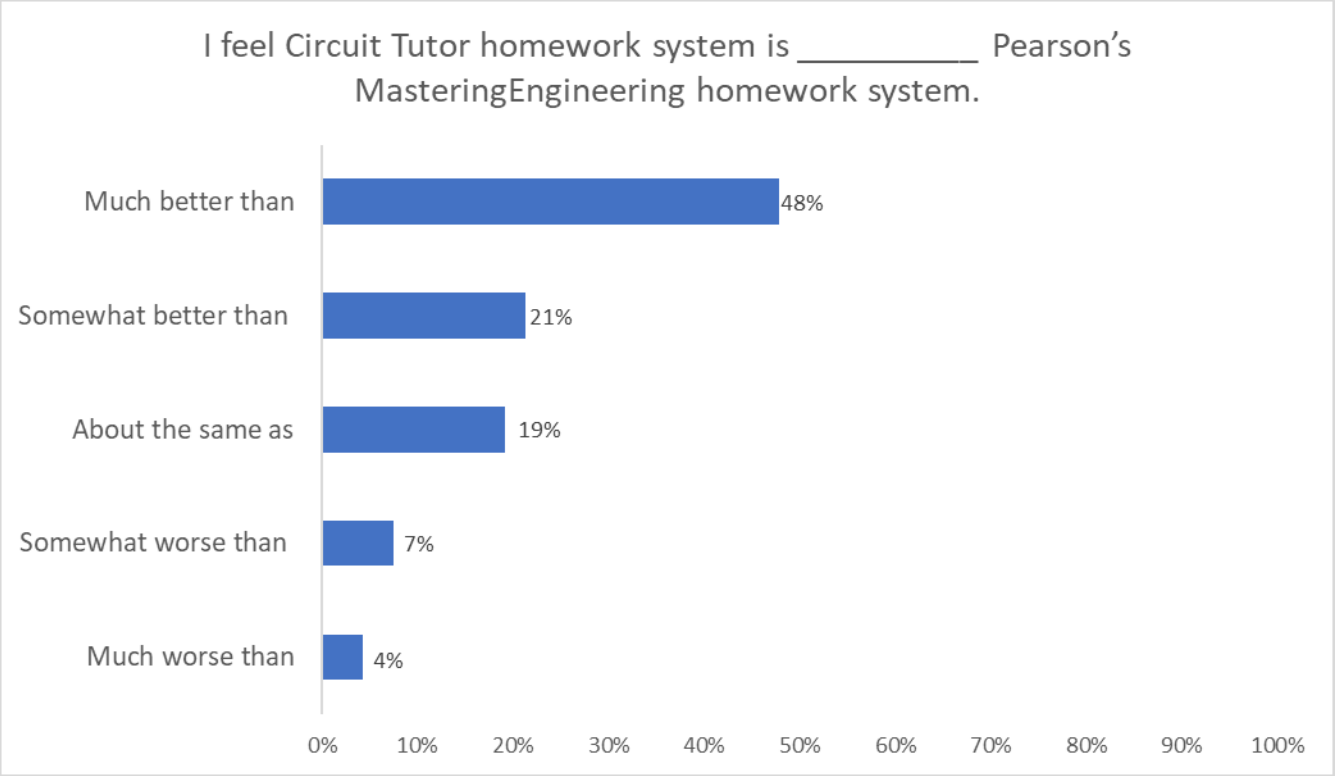
[1] None of the students at MSU completed the survey in the spring 2022 semester.



Note. The percentages represent those students who strongly agreed or somewhat agreed

Students were also asked to report how the CT homework system compared to the Pearson's Mastering Engineering homework system. The findings are reported separately across the fall 2021 and spring 2022 semesters.

Fall 2021. The survey findings showed that 45% (77/171) of the students were not familiar with the Pearson's Mastering Engineering system. Of the students who did use both systems, 48% (45/94) of the students felt the CT system was much better than, 21% (20/94) thought it was somewhat better than, and 19% (18/94) felt the two systems were about the same.



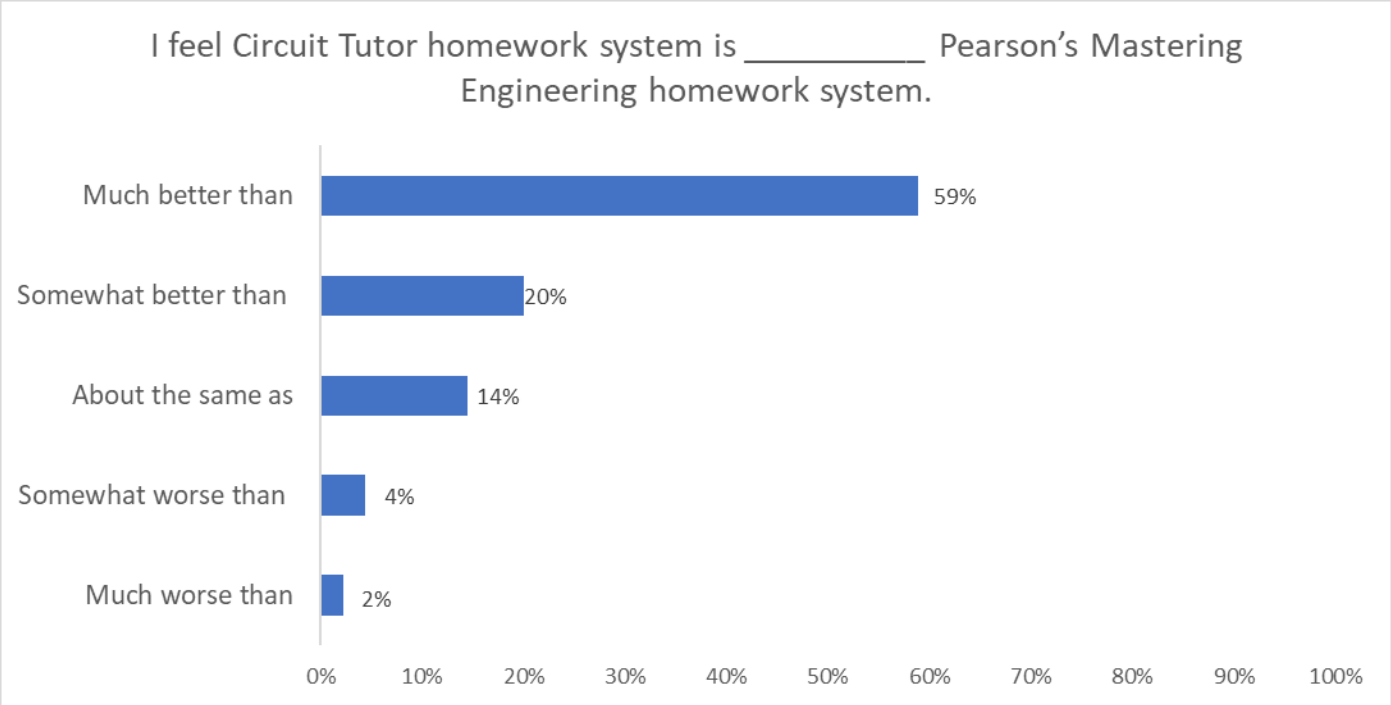
Students who reported using both CT and the Pearson system were prompted with an open-ended question about how the CT system compares to the Pearson's Mastering Engineering system. A total of 29 students responded to this question in the fall 2021 semester. Overall, most students preferred CT over Pearson's Mastering Engineering homework system. While they felt the CT system was more difficult, they also reported that it benefitted them by giving them more practice and ultimately helped them learn the content better. Some themes that emerged for this question included the following: CT is better (provided better explanations/more practice/more examples, videos, interactive) (N=12), CT was a much better program (N=8), and CT was more difficult (N=7).

<u>CT is better (provided better explanations/more practice/more examples)</u>

- While the Mastering Engineering was somewhat easier to interact with, Circuit Tutor was much better at explaining my mistakes and teaching me what I was doing wrong. It was also better at explaining the methods and not just expecting the students to go in knowing everything.
- Pearson is much worse as it lacks explanations, steps when doing a problem and explanations when you get a problem wrong. Also, with the lack of difficulty levels makes it even worse if you did not get the concepts during a lecture.
- I feel that I learned a lot more with Circuit Tutor than with Mastering Engineering, given that in Circuit Tutor it explains your mistakes and allows you to complete a different problem still for full credit which makes it less stressful for the student, Circuit Tutor also provides the student with practice problems before the graded work which can help recall the material, another feature I liked about Circuit Tutor is that It has a Video help which in contrast to Mastering Engineering and other websites I have used it redirects the student to the right video for the problem in question rather than just redirecting to user to the textbook. overall I really liked Circuit Tutor and would confidently say that I learned a lot more from it.

- I believe Circuit Tutor is much better because it gives a better explanation of where you went wrong in your problems. Additionally, Circuit Tutor gives the opportunity for further practice even after finishing the homework unlike Mastering Engineering.
- Circuit Tutor allows for students to try with a different problem each time they run out of attempts, which makes it more possible to get a 100 score. Furthermore, it explains how to avoid mistakes when analyzing a circuit
- It showed good examples which were really helpful.
- It is easy to work on the Pearson problems. It is better to work on Circuit Tutor since there are more examples there. It is good if you are trying to study for an exam.

Spring 2022. The survey findings showed that 42% (84/174) of the students were not familiar with the Pearson's Mastering Engineering system. As shown below, 59% (53/90) of the students felt the CT system was much better than, 20% (18/90) thought it was somewhat better than, and 14% (13/90) felt the two systems were about the same.



A total of 24 students provided additional context to their response on the comparison between CT and Pearson's system. For students who preferred CT over Pearson's Master Engineering, students appreciated the hands-on/interactive approach that provided explanations and feedback, as well as the multiple attempts in solving a problem, which helped with the learning process. The most prominent themes were the interactive nature of the CT software that provided feedback and explanations (N=15) and the unlimited attempts (N=5). Alternatively, students found the CT software needs an updated interface (N=3), while Pearson's interface was better and easier to learn (N=2). Illustrative comments are provided below.

- Circuit Tutor provides much more comprehensive and useful feedback than Pearson Mastering. The user interface of Pearson Mastering is more welcoming than that of Circuit Tutor, but I would much rather use Circuit Tutor in the future.
- Circuit Tutor gives much better explanations about the problems and a step-by-step process for solving than Pearson.
- Circuit Tutor is the best option out of the two learning programs. Pearson's Mastering Engineering is only a system used to assign homework problems and does not give much options for students to interact with content. Circuit Tutor on the other hand, has interactive circuit models, it gives out plenty of advice as to which analysis method should be used, it explains corrections and offers solutions to problems in a detailed manner, and provides more content to students by providing levels in each game so that students can review step by step a specific type of problem. Pearson's Mastering Engineering only offers pictures and models with the information needed for the problems assigned and corrects an answer after a specific number of attempts without an explanation. Circuit Tutor also encourages learning, as it does not penalize the student for generating a different problem or not being able to solve a problem with the attempts given. Pearson's Mastering Engineering does not give this opportunity to students, as they instead get deducted points for each wrong attempt and they are not able to generate a different problem.
- There is no guidance with Pearson's Mastering Engineering it expects you to already know circuits. On the other hand, Circuit Tutor does a great job in explaining and demonstrating a variety of circuits.
- I would say that Circuit Tutor is more interactive and more engaging but also a bit more intimidating since it was something new to me and didn't really seem user-friendly. After a while you do get used to it and it feels nice having the video tutorials and the examples, but at times the sound effects of Circuit Tutor discourage you especially when you make a few mistakes in a row.
- I preferred Circuit Tutor because it allowed me to experiment more with the problems. Also, I do not like that Pearson will deduct points for correct answers to problems but if a mistake was made beforehand you are penalized. Circuit Tutor is better in my opinion because if I was stuck on a problem and made to many mistakes, I could have another problem be generated and get full points for solving it. Also, the YouTube videos were very helpful I grasp concepts quicker with videos than reading.
- I hate that Pearson penalizes you for trying and deducts points for small errors. Circuit Tutor did give you the ability to try without losing points.
- The interface for Circuit Tutor has a lot to improve but I do see a lot of potential if the UI is dramatically improved.
- Circuit Tutor not only gives you unlimited attempts without penalties, but it also shows you what was the mistake that you did during the process. Circuit Tutor gives the option to give up and see the correct process and an explanation of it. On the other hand, while Circuit Tutor is better in some ways, it is bad in others compared to Pearson's Mastering Engineering. Circuit Tutor is harder to navigate because of its simplicity in design. In addition, Circuit Tutor forces you to be super

precise with rounding. Regardless of everything, Circuit Tutor is better than Pearson's Mastering Engineering.

- Unlike Mastering Engineering, it [CT] offered feedback and explanation after failing to correctly answer a problem. It explains how to approach the problem instead of just telling the student the correct final answer
- Circuit Tutor provides the experience and examples for solving different circuits, in Pearson it only gives you a problem to work and if you get it wrong they give you little feedback making it harder and longer to work on homework. With Circuit Tutor, we can see different examples and solutions to learn and apply them on homework for grading, the practice is key to learn. Overall, Circuit Tutor is better because of the practice and examples it provides.
- The things I liked about Circuit Tutor, were the PDF explaining the process at the end of the problem and that if you failed the problem you can always retake it, and for Pearson's system if you somehow wrote something wrong, you get points deducted from the final grade and it can only be taken once, but what I didn't like about Circuit Tutor is how specifically the answer should be, If you put a number wrong or did the procedure somehow wrong, you have to take the problem all the way to the beginning, In my opinion, it should ask for repeating the same problem or to take another one if you are really stuck because for me took hours to complete a problem just because it wasn't specific on what was asking for and I had to redo it from the beginning with new problems.
- Pearson is way more user friendly, Circuit Tutor's idea is amazing, way better than Pearson, but the looks and learning curve of the software by itself is bad. If user interface is changed no issues. Has a lot of potential for easier learning process.

3. HOW DID INSTRUCTORS PERCEIVE CIRCUIT TUTOR TO IMPACT THEIR TEACHING EXPERIENCES?

The instructor survey data presented below was collected in the spring 2022 semester. Generally, the instructors had favorable teaching experiences using circuit Tutor (CT). Overall, 43% (3/7) of instructors reported that CT was much more effective, 43% (3/7) reported that it was somewhat more effective, and only 14% (1/7) said it was about the same as the homework system they previously used teaching at teaching students the topic of linear circuit analysis.

	SPRING 2022 (N=7)
Circuit Tutor is **"much more effective"** than the homework system I previously used at teaching students the topic of linear circuit analysis in my class	43%
Circuit Tutor is **"somewhat more effective"** than the homework system I previously used at teaching students the topic of linear circuit analysis in my class.	43%

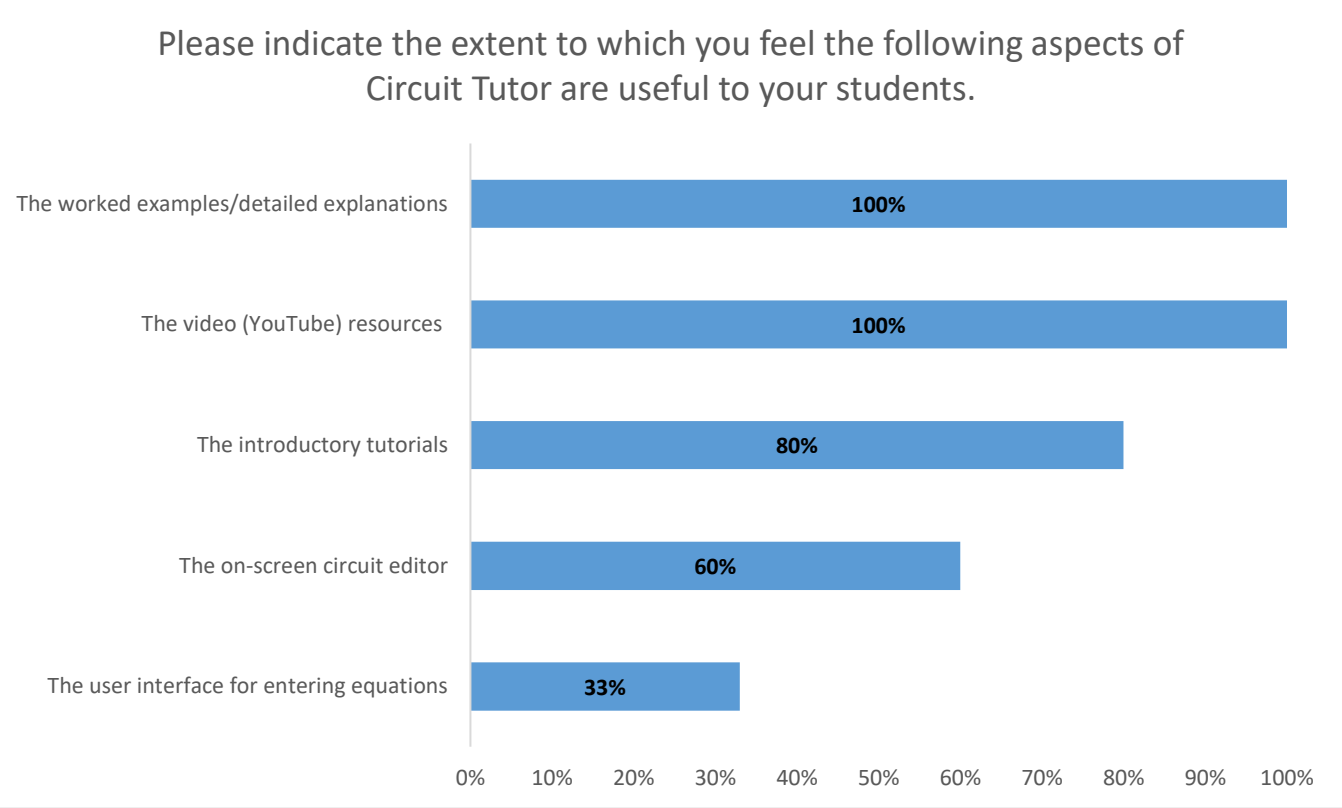
Circuit Tutor is **"about the same effectiveness"** than the homework system I previously used at teaching students the topic of linear circuit analysis in my class.	14%

72% of instructors reported using CT make teaching their class somewhat easier or much easier compared to other types of homework systems used in this class.

4. HOW DID INSTRUCTORS PERCEIVE THEIR STUDENTS TO EXPERIENCE CIRCUIT TUTOR IN THEIR COURSE LEARNING?

Instructors were asked the extent to which they perceived their students were motivated to study linear circuit analysis using CT when compared to the previously used homework system in his/her class. Most instructors (83%; 5/6) reported that their students were somewhat more motivated to study linear circuit analysis when using CT compared to the other homework system.

Instructors were also asked about the extent to which they felt the following aspects of CT were useful to their students. As shown below, all instructors (100%; 5/5) perceived the worked examples/detailed explanations and video tutorials were useful to their students. The next highest rated features of CT that instructors perceived useful to their students were the introductory tutorials (80%; 4/5) and on-screen circuit editor (60%; 3/5). The lowest percentage of instructors (33%; 2/6) felt the user interface for entering equations were very useful.



Note. The percentages represent those instructors who found these components extremely useful or very useful to their students.

5. TO WHAT EXTENT WERE STUDENTS AND INSTRUCTORS SATISFIED WITH CIRCUIT TUTOR?

STUDENTS

Students were asked open-ended questions in their end of the course surveys in the fall 2021 and spring 2022 semesters, providing a more detailed understanding of their experiences with using Circuit Tutor (CT). These data served as supplemental evidence to their quantitative assessment of the platform.

Questions asked were:

- What do you like best about Circuit Tutor?
- What are some of the recommendations you would make for improving Circuit Tutor?

WHAT DO YOU LIKE BEST ABOUT CIRCUIT TUTOR?

Fall 2021. A total of 144 students responded to this open-ended question. There were multiple things students reported liking about CT, some of which overlapped in their overall responses. The main themes that emerged were 1) explanations/instant feedback/interactive properties (N=58), 2) allowing multiple attempts (n=48), 3) video tutorials (N=20), 4) user friendliness of the software (N=17). Illustrative comments from these emergent themes are included below.

Explanations/Instant Feedback/Interactive Properties

- The helpful and thorough explanations in the tutorial. That when you get a question/problem incorrect, it explains to you why it is wrong, and what to change.
- I liked how easy it was to learn using it. I had a much better time learning circuits with a program telling me when I was wrong the moment I was wrong instead of finding out about it later.
- It was nice that it gave me feedback when I did it wrong so that I could see what I did wrong.
- I like that Circuit Tutor is an online based homework that lets you interact & also teaches you about engineering.
- I like that it's interactive and it doesn't make you read a bunch of unnecessary things that just overwhelms me and makes me think something is more complicated than it is.
- It gave me a clear explanation of what needs to be done or were I made a mistake, which helps me a lot to piece in puzzle the problems out to see where I'm making mistakes or where I can better calculate solutions.
- The explanations when you got a problem wrong and step by step explanations of how to do them.

Multiple Attempts

- The ability to do as many problems as necessary to understand the concept.
- I like how it basically gives me endless problems to practice and enhance my abilities to solve and manipulate circuits.
- I like that Circuit Tutor essentially has an unlimited amount of problems to practice. Before tests I would always practice on Circuit Tutor. It is also much more engaging than regular homework and I was more motivated to complete Circuit Tutor.
- The fact that you have unlimited tries is helpful, and that each attempt is followed by an in-depth summary.
- I liked that it would create as many problems as you needed to work through, to help with studying.
- My favorite part about Circuit Tutor was the replay ability. In Mastering Engineering, I may have 5 tries to get the correct answer for a problem, but I lose points for every attempt. This is not conducive to learning since it scares students from trying if they do not get the answer right on the first try. In CT, I may lose all points on my first try, but then I can try again and again as many times as I want until I get 100%. This is the best part about CT, and any learning platform that does not employ this strategy undermines the learning of all students who use it.
- The opportunity to have unlimited attempts without risking grades; learning from errors, is what really enhances learning.

Video Tutorials

- I like the video explanation because it explains by detail how to work with each question.
- The ability to retry multiple circuits without a graded penalty, as well as the walkthrough YouTube Video.
- The video help was one of the most useful things to go to when being stuck on a problem.
- I like the Video that explains how you approach a problem. It was also practice for my exams.

User-friendliness of the Software

- User friendly and accessible
- Easy to learn
- I liked how easy it was to learn using it. I had a much better time learning circuits with a program telling me when I was wrong the moment I was wrong instead of finding out about it later.
- Easy to use
- The equations were easy to set up
- The layout and approach to each game
- I learn a lot quicker with it
- Ease of use, streamlined solving process, I don't have to draw circuit diagrams by hand

Spring 2022. A total of 157 students responded to the open-ended question. Students had several things they liked about CT, the most predominant things being the interactive feedback/explanations (N=65), unlimited tries at solving different problems with no penalty (N=42), multiple levels of difficulty (N= 25), YouTube videos (N=28), examples (N=13), and positive sound effects (N=10). Illustrative comments are provided below that support these qualitative themes.

Interactive feedback/explanation on problem and its solution

- It was a lot more interactive than traditional homework. It also helped guide you through each problem.
- I liked that it was like a game because it made my homework slightly more fun.
- The ability to go through multiple examples and have personal walk-throughs provided for each problem were extremely helpful in learning Circuits.
- I liked how the explanations were extremely useful, especially when you failed a problem.
- I really liked the feedback from problems I failed or gave up on.
- I liked how it made us go step by step when solving a circuit as I thought I learned the material better that way.
- There is always a way to figure out how to get the answer. When I do the homework in Canvas or use Pearson's system for my physics class, I won't get the credit or an explanation on how to do it if I didn't understand the question in the first place. Giving a work-through of the answer is much more conducive to learning than punishing me for not knowing how to solve it initially.
- I liked how I was able to get direct feedback on every part of the question so I could see where I was going wrong immediately, instead of finding out at the end then having to figure out where I went wrong.
- I like that Circuit Tutor explains your errors while you go through the simulations. It fills in the gaps of my understanding when I don't understand my mistakes.
- Depth of explanations and step-by-step guidance
- The explanations it gives if I get a problem wrong as they really help me learn the material better and at my own pace.

- I appreciate many facets of Circuit Tutor. I love the step-by-step explanations of problems that I got wrong so I can clearly see my mistake and fix it later.
- I like that the software is interactive to work with and allows the student multiple ways of tackling the problem instead of making them solve it a certain way.
- I really like the feedback it gives when you don't manage to solve a problem, it really helps with learning from the mistake. Plus, the next problem it gives is usually similar enough that you can more easily avoid the same mistake whilst still being different enough that you get the extra practice of having to work through another problem.
- I like that it allowed me to learn how to solve problems by making mistakes and checking to see what was wrong; on traditional homework assignments if you answer something wrong, you wouldn't even know until it comes back graded. Often times you don't even understand what you did wrong in that situation, but with Circuit Tutor you get to see where you went wrong right away, and you can look at the exact solutions to the problems to see how to do it right.

<u>Unlimited tries at solving different problems with no penalty</u>

- The ability to continue trying a problem and not being penalized. It really encourages students to properly check their work and understand what they're doing to come back and tackle it again. Practice makes perfect and allowing more practice without penalty is an advantage.
- I like that you can try as many problems as you like until you get it right.
- I like how it gives multiple attempts.
- The ability to learn and make mistakes as many times as possible to learn.
- The best part was the unlimited amount of tries.
- I liked the unlimited problems that I could use to practice.
- I liked that I was able to learn from my mistakes and keep attempting the questions without losing credit. I was able to learn what I was doing wrong and how I was supposed to do the problems.
- It was easy to understand, use, and allowed me to get full credit for problems I previously got wrong.
- The amount of extra practice I could get through the infinite generation of problems to solve for each topic we learned in class.

<u>Multiple levels of difficulty</u>

- I liked how it generates a lot of different problems at different difficulties.
- I like the levels of difficulty, there were a lot of things I didn't understand in class that I did understand after Circuit Tutor and it was a fantastic learning tool.
- The variety of questions allowed me to progressively learn how to solve the problems at a pace I always felt was reasonable.
- I liked how Circuit Tutor provided increasing difficulties in homework. The easy level really helped establish base information to get a feel of the type of problems in later stages. Additionally, the growing difficulty provided more realistic test problems that required students to apply more techniques and more work in order to not be too easy.

- It is well organized, and concepts build well when increasing difficulty levels.
- I like that you can learn through different difficulties and go along with the videos.
- I liked the multiple levels of difficulty offered and how there were plenty of different problems at each level.
- The multiple chance system and the ability to start easy and move to hard.
- How it gives problems from different difficulty levels.

YouTube videos

- The video help was useful and often helped when a small flaw in the work was preventing a correct answer.
- Its help videos and a chance of viewing an explanation of the problem with its solution.
- The video tutorials made the hardest questions manageable.
- I like the YouTube videos showing different examples. Those helped a lot.
- I like that there are multiple examples and follow-along videos that provide detailed explanations. It is well organized, and concepts build well when increasing difficulty levels.
- I like that you can learn through different difficulties and go along with the videos.
- It was by far the videos that accompanied the assignments, they are extremely helpful and solve almost all doubts that one might have about a problem.
- I also liked the YouTube videos professor Skromme posted, they were extremely helpful.
- The video tutorials also helped tremendously when I was stuck on a problem; the instructor provided clear directions on using the program.
- I liked the YouTube videos that would help you through the levels when I got stuck.
- The videos were very helpful, especially for determining how and what the software wanted.
- I like that there are instructional videos with similar problems, I also like those new problems can be generated if I have made too many mistakes.
- I like how there is immediate help when I got stuck on the problems. Sometimes when doing homework, you can get stuck and must wait until office hours to get help, but the YouTube videos were there always to answer my questions.

Examples

- I like the examples that you can look at or watch to better understand the software.
- I like that there are worked examples for each level. It was helpful to look at an example before starting a level to get a feel for what was to come.
- Giving physical examples that allow me to make mistakes and to figure out where I need to work on the specific problems that I was studying that week.
- The examples were very helpful
- The amount of examples and practice problems, and when you don't know how to solve the problem you can give up to learn what you did wrong and learn from it.

Sound Effects

- The sound effects were pleasing.
- I liked the sounds for getting things correct.
- Sound effect. I feel so proud every time I hear people cheering me on.
- The little cheer after completing each level.

WHAT ARE SOME RECOMMENDATIONS YOU WOULD MAKE FOR IMPROVING CIRCUIT TUTOR?

Student were asked to make recommendations for improvement to the CT homework system. The open-ended responses are included in the sections below.

STUDENTS

Fall 2021. A total of 127 students completed this question. The themes that emerged for recommendations for strengthening Circuit Tutor were updating the interface (N=27), allowing for more attempts/errors (N=14), making it Mac friendly (N=8), abbreviating the tutorial/clearer instructions (N=16).

Updating the Interface

- Better interface for building the circuits.
- The interface presents a learning curve. With the drag and drop options I began to learn what square to use rather than what the parts of equations meant. Even when I did well on Circuit Tutor and was able to do master without any difficulty, when it came to the test I completely forgot how to write the equations.
- I would improve the look of the site, it still feels like it's a decade old, even though it isn't.
- Improvement on the UI to be clearer and less restrictive. creating multiple windows on top of another is strange. Also, clearer instructions on how to use the UI when first starting out or when new things are introduced.
- Updating the graphics.
- Making the interface clearer, especially when it comes to how to rearrange the circuit.
- I will like the application to be more attractive with animations. That is, adopting an animated UI into Circuit Tutor. I know it can take time to build it to such a level and that is why I highly recommend it. Adding animations to solutions or graphics can increase user's interest in the app.
- The interface needs to be improved as it is counter intuitive and ugly. The drag-and-drop equation system can be frustrating to use, and it would be much faster if one could type in equations instead.
- I would recommend having a dark mode or a dimmer mode for when students are working on it late at night and are not blinded by the light of the system. Maybe having two windows allowed as well, so the students can follow along on one window and see how to work out the problem in real time.

- Allow people to scroll during the explanation instead of holding and dragging to navigate. Maybe make a viewing of a worked example required, or an explanation video to aid in the approach and make videos that show more of the harder difficulty questions of varying degrees.

Allowing More Attempts/Errors

- One area that could be improved is increasing the number of attempts per problem. This would allow students have more opportunities to get the problems right. Or instead of having just 3 strikes may be use half points which would still allow the student to continue the problem.
- One area that could be improved is the number of attempts per problem. This would allow students to have more opportunities to get the problems right. Or instead of having just 3 strikes may be use half points which would still allow the student to continue the problem.
- Allow more mistakes before you lose credit of the whole problem. There are many parts to one problem, and you can lose all progress if you mess up on one small area.
- Give us a few more chances to make errors especially in harder levels. it was so frustrating when I would make one mistake here or there and I would have to restart the whole problem even when I already knew the answer to the current one.
- I think that the system where if you make more than a certain number of mistakes you must try a new problem should be abolished. Often I work out a long problem and make a dumb mistake only to rework another problem and go through the same struggle again, which is tedious.
- I would give more attempts and make it so that you don't lose credit when you make a sign error. I would make sign errors that would force me to restart all the time and it would drive me insane.
- For those longer problems or questions especially in the middle of the semester were the plans may become more difficult and longer due to matrices or other calculations it would be much more helpful to have those problems be more forgiving by giving multiple attempts per their sections. This is since you could go along the problem and hit a roadblock and then fail one problem has three times and all your progress I was made in the past half an hour he's gone. This is especially difficult when your assignment is due the next thing in the morning. Possibly having more times available for the sections could be very useful it was very stressful when they had the three attempt problems when You are deep into a problem. And if this problem is given and they do feel it for not receiving credit possibly give me an explanation and answer solution there to tell him this is what the answer should have been saying give up you get the answer. So possibly they may go on and proceed to look into what they need to do for the problem just for practice.
- I would recommend that at the time we missed all the attempts that we should not re do the problem once again, because we lose plenty of time re-working with the same problem with different values.
- The amount of errors you can make needs to be adjusted with how hard the problem is.
- Allow more errors, as it is super frustrating when you are one step away from finishing the problem but then use all of your allowed errors and don't get the problem for credit.

- Add more chances for error rather than just restating the entire problem after two mistakes, even if they were very minor like forgetting a negative sign. and highlight the wrong input so there no guessing.

Abbreviating the tutorial/clearer instructions

- I think that the tutorial section is too long for some topics. The tutorial needs to be more specific instead of having a lot of information.
- Make the slides a little shorter each slide because when one page is full of too much information, the reading will seem like a hassle to anyone reading it but when it is more spread out it is easier to get through and understand.
- There's a lot of wording in the lectures. This was difficult for me to learn as I like more visual learning.
- A lot of the pre-tutorials are incredibly long and tedious to go through, reading some of them alone took an hour for me to fully understand what was trying to be described, which made it hard to find them useful since it was such a long block of text. I'd much rather have the readings be interspersed throughout the assignment where it covers material that will be directly useful to the future problems.
- Some of the features need to be explained better when they will be used in problems. For example. I didn't know right click was used for anything until I asked a friend.
- In the tutorials, I wish they were more detailed on how to navigate the software and how to perform the math needed for matrixes.
- When being given a new tool like killing sources/source transform/ changing required voltage to current, I would include a small 3 step tutorial within the program that helps you know what to click in order to do the transformation because many of my mistakes were clicking the wrong buttons even though I knew the concept.
- To make it easier to modify and explain how to do something before the game rather than showing the student after they gave up. It was very irritating to mess up a ton on these homework's when I knew what to do on paper but the simplification and excess things to do on Circuit Tutor made it difficult to solve the problem. Very frustrating.

Spring 2022. A total of 156 students completed this open-ended survey question prompting for recommendations. The main themes that emerged mirrored those from fall 2021: updating the interface/software (N=53), more attempts/not having to reset problem when missed (N=26) and make the instructions/tutorial shorter (N=16). Illustrative comments are provided below.

Updating the Interface/Software

- Working out some software bugs that cause it to be unusable at times.
- When viewing the solution for a problem, the scroll feature didn't work well.

- When the circuit gets complicated sometimes in mesh analysis the units and numbers of the elements overlap and cannot be seen well. I would recommend reviewing this and fixing the display.
- Updating the GUI would be very helpful. The program felt old and dated and just not up to current modern-day standards, looks wise.
- Too many bugs, the format looks like it's from the 90's.
- The user interface was frustrating at times and some of the allotted errors was unforgiving in certain games. I would come close to the end of the problem and make a dumb mistake and would have to start over after losing credit for the problem which took time to get to the end.
- The software can tend to be pretty buggy, but nothing about how the program is set up needs to be changed.
- The program will sometimes crash if left open for too long or if my laptop closed.
- The only complaints would be the outdated format, but with experience and the YouTube tutorials it is still navigable.
- The look of Circuit Tutor's windows app could use some work and the circuit simplifying tool can be very unintuitive at times, depending on the task.
- The interface is hard to understand. Despite having circuit knowledge, I don't know what to do at some point (e.g., it's not clear the software want me to only perform the source transformation while I understood I can freely transform the circuit).
- Sometimes the software would stall when I would switch in between tabs to do calculations or watch example videos. This was very frustrating as I would be unable to complete a problem even if I was very close to finishing it, instead forced to close the software as it was unresponsive. The tutorials were not very engaging to me so I never did them.

<u>Allowing More attempts/Not Having to Reset a Problem when Missed</u>

- To modify that [problem] you must reset the whole problem if you miss.
- One thing would be to allow more attempts on some levels. Sometimes I only got 2 attempts and I knew the answer on the 3rd for example.
- The errors should be divided into minor and major errors and a higher allowance for minor errors should be given. If one portion of a question is completed correctly students should not have to redo this section if they give up on a later portion. If a student completes all but one section of the question they should receive partial credit for the portions they did complete.
- Sometimes the Circuit Tutor assignments can take hours to do. There were times where I would get through the entire problem and then got the last part of it wrong and had to redo the entire problem for credit. Making the assignment shorter and giving more attempts before losing credit may be more useful.
- [Give]partial credit; more room for error! There were countless problems that I lost all credit for after investing over half an hour into, simply because I made two mistakes at the very end of a problem. This is extremely ineffective for learning and made me not want to do the assignments at all.

- More chances for mistakes or when you got it wrong and must do it again, you start from the mistakes instead from the beginning!
- It would be great if the number of attempts per equation did not exist. Having three tries or so before losing credit for the entire problem is horrible, and it just makes the whole experience frustrating. Rather than focusing on the content, I am just trying to complete the circuit without losing credit.
- Extending the number of tries per attempt to help minimize the errors.
- I would make it so you don't have to restart every level each time. Make more check points.
- I would like more incorrect attempts. There were times where I would have to do the whole problem over because I made 2 accidental mistakes.
- I personally do not like how you can lose all credit for a long problem (like AC analysis) for simply messing up a voltage divider or mesh analysis for a circuit. I don't think credit should be lost for elementary pieces of circuit analysis.
- Give unlimited attempts at a problem. Especially when you are so close to solving it and there is a slight mistake, you have to start over which is unfortunate.

<u>Making Instructions/Tutorials Clearer/Shorter</u>

- The manuals, instructions, and sometimes the tutorials could be cut down. They're very comprehensive, but sometimes they're way too much to read. I generally ignored the instructions if they were too long, then figured out how to play the game by trial and error.
- The web tutorials were very wordy and technical. It was very hard to understand the concepts.
- Some instructions especially in the Norton and Thevenin assignment was not clear even with the YouTube video on how to change up the circuit.
- While the app itself is great, learning to use Circuit Tutor was annoying, because the circuit editor functions often had instruction manuals that were 3+ pages in length. Instructions for a circuit editor shouldn't take more than 1 or 2 pages in my opinion. Essentially, try to make the circuit editors more intuitive/user friendly.
- Currently, it is very time-consuming to read through a tutorial. If some of the more detailed information wasn't immediately present but was still accessible via dropdown menus or otherwise, this would be more user friendly in my opinion.
- I would recommend informing students how long the introductory tutorials can sometimes take. I would also make a summarized version of the tutorials available instead of the full-length tutorials before starting a game. It was frustrating when I didn't have much time and I just needed to finish my homework, but I couldn't even start it because I had to go through a pretty lengthy tutorial. I would at the very least let the students know how may pages are in the tutorials as oftentimes I didn't even know how much longer the tutorials were. It was hard to manage time around this if I didn't even know how long they were.
- I wish the instructions were clearer. Sometimes it would be a whole page essay and most students would not take the time to read it, so it should be more concise and clearer.

INSTRUCTORS

Overall, the instructors were satisfied with their experiences using Circuit Tutor (CT) as shown by the high percentage of instructors who would recommend CT to other instructors (100%; 7/7). Further, 100% of the instructors reported having adequate administrative support (e.g., enrolling students, creating TA accounts, setting up assignments, downloading grades, monitoring progress, etc.)

Faculty reported strengths and "areas that need improvement" based on their experiences with CT in open-ended survey question responses. Illustrative comments are highlighted below.

CIRCUIT TUTOR STRENGTHS

A total of six of the seven faculty responded about Circuit Tutor (CT) strengths. Instructor comments included the way in which CT helped students achieve a deeper understanding of how circuits work through the guidance provided, the feedback, and the ability to practice. Some illustrative quotes are below:

- It is effective in helping students understand the more complex topics, from concepts to techniques.
- The greatest strength of Circuit Tutor I think is that it guides the user to get the right answer. Also, as instructor, when I assign a homework on a specific topic I know for sure that the student will use that specific method, while if I assign it in a different system, the student will tend to use the method that he/she is more familiar with, or it is easier to use.
- Providing feedback to students as soon as they made an error.
- It is a very effective way to get students to practice the concepts. Most students I talk to enjoy using the tool and especially in the more well-established activities (Nodal and Loop Analysis) I see a huge improvement in understanding after completing the Circuit Tutor assignments. I love the cheers when they get it right. I love that they get unique problems, so they are forced to do the work and not just copy. I love that they get multiple chances (although I'd like to increase the number of chances they get).
- The explanations and the walk through that it does to the students. Also, the enormous number of examples.
- The tutorials

RECOMMENDATIONS FOR IMPROVEMENT

Instructor comments regarding aspects of CT that could be improved in the future include addressing the compatibility between PCs and Mac devices, updating the interface, giving students more chances on the complex problems, evaluating students based on how much they have achieved, and modifying the process of registering students in CT. Some illustrative quotes that emerged from the open-ended responses are provided below.

- Compatibility with Apple IOS which tends to be popular with students.
- To have a more user-friendly interface, possibly making it easier for the user for "form" equations. I do not have any suggestions on how to achieve that.

- The type of problems that CT covers is somewhat limited.
- The software needs to be moved to the ASU cloud computing - we should not need to ask students to download the software. For the more complex and difficult problems, I'd like to give the students more than 3 chances - there is nothing more frustrating than getting most of the way through a difficult problem and then having to start all the way at the beginning.
- Evaluating the student based on how much they achieved and not giving them feedback while they solve the problem. CT is designed to teach not evaluate the students, but it is used by instructors as an evaluation tool although it is mainly not designed to do so. This is the biggest weakness I can see in CT (It is presented as both a learning and evaluation tool, although it is mainly designed to educate much more than to evaluate).
- The process of registering students in Circuit Tutor needs to be improved. There were a few times when I could not register my students or once I registered my students I did not receive the download file which contained my students' registration numbers.

CONCLUSIONS

Document review and surveys confirmed that all lead instructors successfully implemented the CT system within their classrooms. Taken together across both semesters, 95% (95% in fall 2021; 94% in spring 2022) of the students across all institutions strongly agreed or somewhat agreed that CT was useful in helping them understand the class content, 84% (89% in fall 2021; 79% in spring 2022) prefer CT exercises to other homework systems, and 77% (82% in fall 2021; 71% in spring 2022) agreed to the same extent they would like to use CT again. Furthermore, across both semesters, 94% of students (96% in fall 2021; 92% in spring 2022) strongly agreed or somewhat agreed the coloring nodes and mesh currents were useful in their learning, while 93% (94% in fall 2021; 91% in spring 2022) felt having multiple successive levels of difficulty were useful to that same extent. The instructor findings showed that 100% of them would recommend that other institutions use CT and felt the administrative support was adequate. Additionally, 86% of instructors reported that CT was much more or somewhat more effective than the other homework system previously used to teach linear circuit analysis and 72% reported using CT made teaching their class much easier or somewhat easier compared to other homework systems used to teach the class. Lastly, 100% of the instructors reported the worked examples/detailed explanations and video (YouTube) resources were extremely useful or very useful to their students. Overall, both students and instructors were satisfied with CT and they provided constructive feedback on ways to improve it even more.