CIRCUIT TUTOR EVALUATION REPORT: YEAR THREE

FINDINGS AND RECOMMENDATIONS

Arizona State University

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INTRODUCTION

Program overview

Researchers at Arizona State University (ASU) led by Brian Skromme in the School of Electrical, Computer, and Energy Engineering, are 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 required courses in many engineering majors. The tutoring system, Circuit Tutor, 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 an analysis of student progress, feedback, and subsequent performance. The system's effectiveness is also examined comparatively using other products such as WileyPlus software and traditional classroom textbooks.

During fall 2020 and spring 2021, all four of the participating universities provided students with Circuit Tutor as an instructional support to their courses.

Evaluation Methods

The external program evaluation examined the outcomes of the fall 2020 and spring 2021 courses. For the third 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 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?

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

The charts below display the institution, course name, and student count for the fall 2020 and spring 2021 courses targeted in this study. The charts are separated by Circuits I courses that were only taught by ASU instructors in the fall 2020, Circuits I courses taught by instructors in fall 2020 and spring 2021 across all partner institutions, and courses only taught by instructors in spring 2021, including two Circuits I courses at ASU and 1 Circuits II course at UTEP.[1] In total, across both semesters, there were 30 Circuits I courses taught, reaching 1,434 students and one Circuits II course, reaching 40 students. It is important to note that not all instructors utilized Circuit Tutor at the same rates and therefore some students utilized it more than others.

FALL 2020 ONLY

The EEE 202 (e.g., Circuits I) courses below were only taught by ASU instructors in the fall 2020 semester, including a total of six Circuit I classes reaching a total of 256 students.

Course Number	Instructor	School	Student Count
EEE 202: Circuits I	Zhaoyang Fan	ASU	45
EEE 202	Diedre Meldrum	ASU	37
EEE 202	Chihan Tepedelenlioglu	ASU	47
EEE 202	Yu Yao	ASU	49
EEE 202	Suren Jayasuriya	ASU	29
EEE 202	Hongbin Yu	ASU	49
Total			256

FALL 2020 AND SPRING 2021

The Circuits I courses below were taught by instructors across all University sites in both fall 2020 and spring 2021 semesters including a total of 11 Circuits I classes in the fall 2020 and spring 2021 semesters, reaching a total of 1,076 students across both semesters.

[1] The courses were split up in this manner in efforts to make the table content more digestible to the readers.

Course Number	Instructor	School	Student Count		
			Fall 2020	Spring 2021	Total
EEE 202 (2 classes – fall 2020; 1 class -- spring 2021)	Amhed Ewaisha	ASU	72; 79	67	218
EEE 202 (2 classes – fall 2020; 1 class spring 2021)	Shamala Chickamenahalli	ASU	51; 52	99	202
EEE 202	Dragica Vasileska	ASU	44	50	94
EEE 202	Brian Skromme	ASU	51	101	152
EEE 202: Circuits I (1 class – fall 20) EEE 202 (3 classes – spring 21)	Marnie Wong	ASU	50	49; 50; 50	199
EEGR 202 – Electric circuits	Gregory Wilkins	MSU	25	25	50
EEGR 202	DeAnna Bailey	MSU	21	20	41
EE 2350 – Circuits I	Hector Erives-Contreras	UTEP	28	33	61
EEE 3111 – Introductory circuits	Petru Andrei	FAMU	29	30	59
Total			502	574	1,076

SPRING 2021 ONLY

The courses below were only taught by instructors in the spring 2021 semester, including two Circuits I courses at ASU (102 students) and one Circuits II course at UTEP (40 students).

Course Number	Instructor	School	Student Count
EEE 202: Circuits I	Meng Tao	ASU	51
EEE 202: Circuits I	Gabriele Formicone	ASU	51
EE 2351 Circuits II	Hector Erives-Contreras	UTEP	40
Total			142

The list of tutorials utilizing Circuit Tutor during fall 2020 and spring 2021 included the following:

- 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 Simplification
- Impedance Simplification
- AC Node Equations
- AC Node Solutions
- AC Mesh Equations
- AC Mesh Solutions
- AC Analysis
- Bode Plots
- Laplace Transforms
- Inverse Laplace Transforms

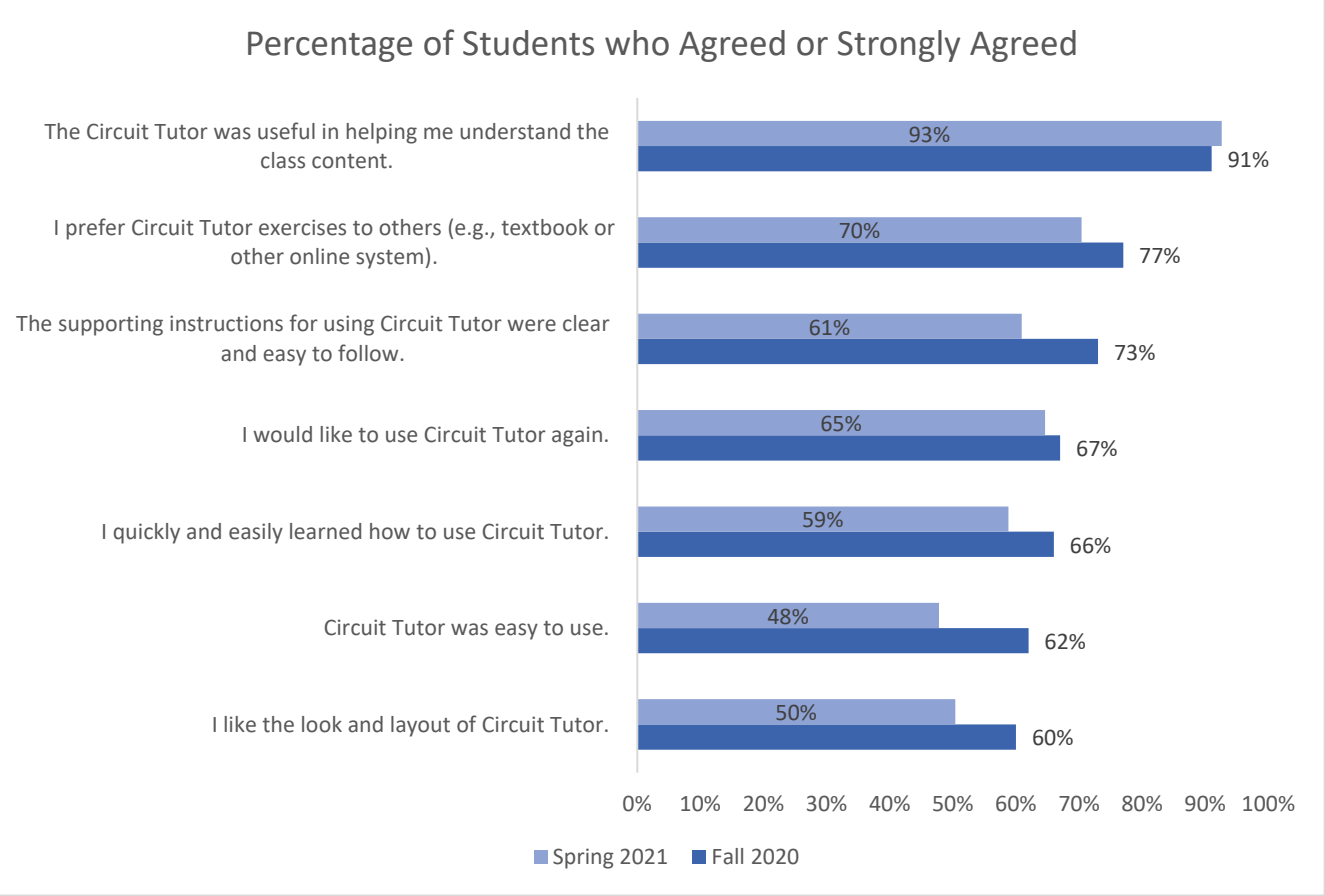
2. HOW DID STUDENTS PERCEIVE THE UTILITY OF CIRCUIT TUTOR IN SUPPORTING THEIR COURSE LEARNING?

Surveys were sent to students at the end of the fall 2020 and spring 2021 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 Circuit Tutor and their satisfaction with Circuit Tutor across both semesters; however, some additional questions were added in the spring 2021 student survey. All the survey data from both semesters is presented below.

	Fall 2020	Spring 2021
ASU	61% (70/114)	59% (173/295)
FAMU	8% (2/26)	57% (17/30)
MSU	38% (38/65)	56% (31/55)
UTEP	54% (15/28)	57% (17/30)

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 tables above. Surveys were only sent to a select sample of instructors at ASU and therefore those numbers also vary from the tables above.

Overall, students had very favorable experiences using Circuit Tutor across the fall 2020 and spring 2021 semesters. At least 48% of students in the fall 2020 semester and 60% of students in the spring 2021 semester agreed or strongly agreed with all these survey items. As shown in the figure below, the highest percentages of students across both semesters agreed or strongly agreed that 1) Circuit Tutor was useful in helping them understand the class content (fall 2020: 91%; Spring 2020: 93%), 2) they preferred Circuit Tutor exercises to others (fall 2020: 77%; spring 2021: 70%), and 3) supporting instructions for using Circuit Tutor were clear and easy to follow (fall 2020: 73% : spring 2021: 61%).



As shown in the table below, there was slight variation in student perceptions of the utility of Circuit Tutor across universities. In the fall 2020 semester, the most favorable perceptions of Circuit Tutor were in students at UTEP (75%) and MSU (70%), whereas in the spring 2021 semester, the most favorable perceptions were among students at ASU (64%) and MSU (64%). It is important to be mindful of the sample sizes for each of the semesters presented below when observing the percentages.

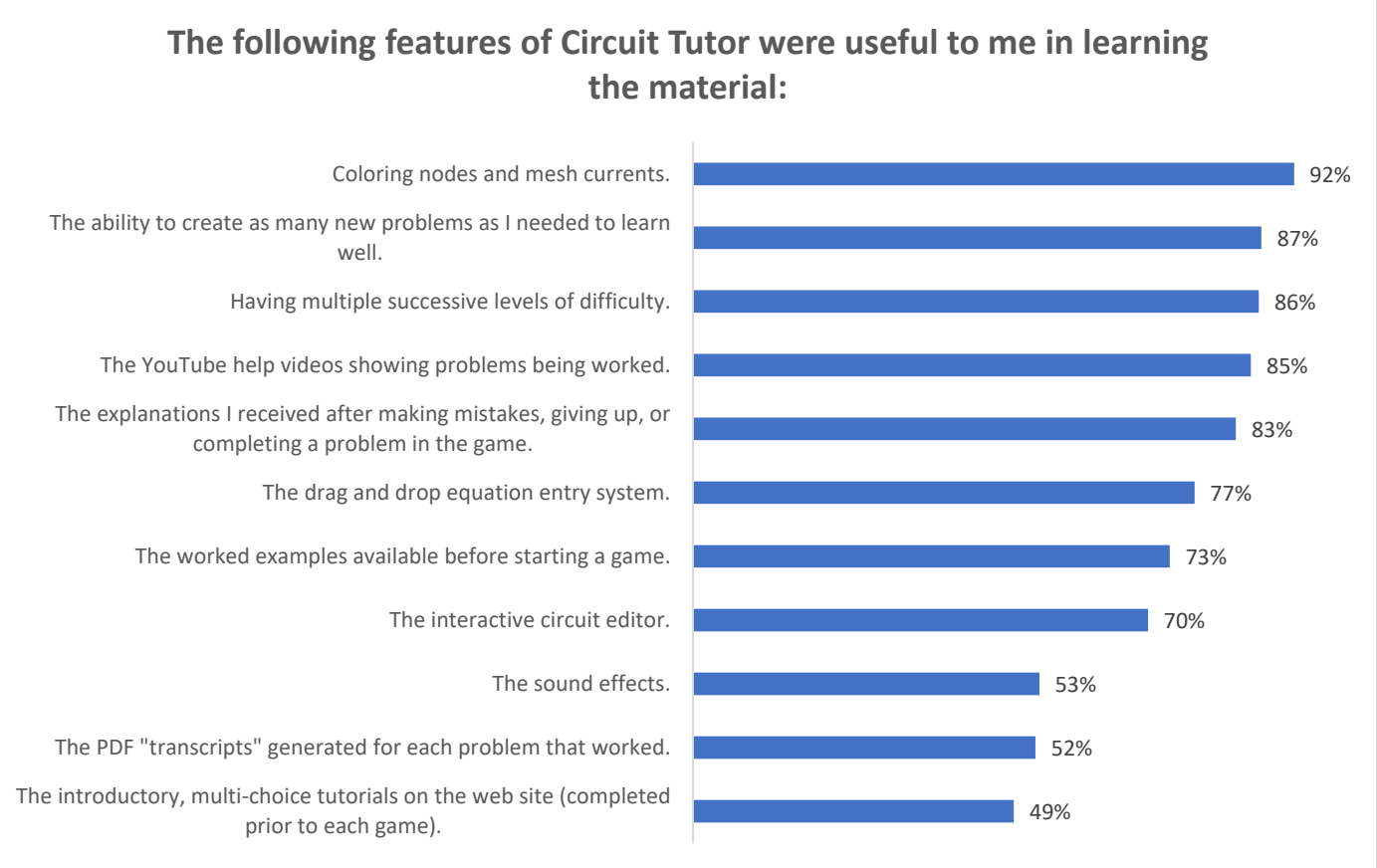
Survey Items	ASU (N=173)		FAMU (N=17)		UTEP (N=35)		MSU (N=31)	
	F20 N=70	S21 N=173	F20 N=2	S21 N=17	F20 N=15	S21 N=35	F20 N=38	S21 N=31
1. The Circuit Tutor was useful in helping me understand the class content.	87%	96%	100%	94%	100%	86%	91%	84%
2. I would like to use Circuit Tutor again.	77%	66%	50%	42%	78%	51%	63%	58%
3. I prefer Circuit Tutor exercises to others (e.g., textbook or other online system).	84%	76%	50%	64%	72%	57%	66%	58%
4. I quickly and easily learned how to use Circuit Tutor.	64%	64%	50%	53%	64%	37%	64%	58%

5. The supporting instructions for using Circuit Tutor were clear and easy to follow.	61%	66%	50%	59%	86%	63%	70%	61%
6. Circuit Tutor was easy to use.	57%	51%	100%	53%	71%	34%	61%	68%
7. I like the look and layout of Circuit Tutor.	58%	48%	0%	59%	57%	31%	75%	62%
AVERAGE % who "agreed somewhat" or "agreed strongly"	**69%**	**67%**	**57%**	**61%**	**75%**	**51%**	**70%**	**64%**

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

Based on feedback from the PI, some additional questions were added to the student survey in the spring 2021 semester. Students were also asked about the utility of specific features of Circuit Tutor when learning the material. Almost half of the students (49%) agreed or strongly agreed that all aspects of Circuit Tutor were useful. The highest percentages are shown below:

(1) Coloring nodes and mesh currents (92%)
(2) The ability to create as many new problems as needed to learn well (87%)
(3) Having multiple successive levels of difficulty (86%)
(4) The YouTube help videos showing problems being worked (85%)
(5) The explanations received after making mistakes, giving up, or completing a problem in the game (83%)



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

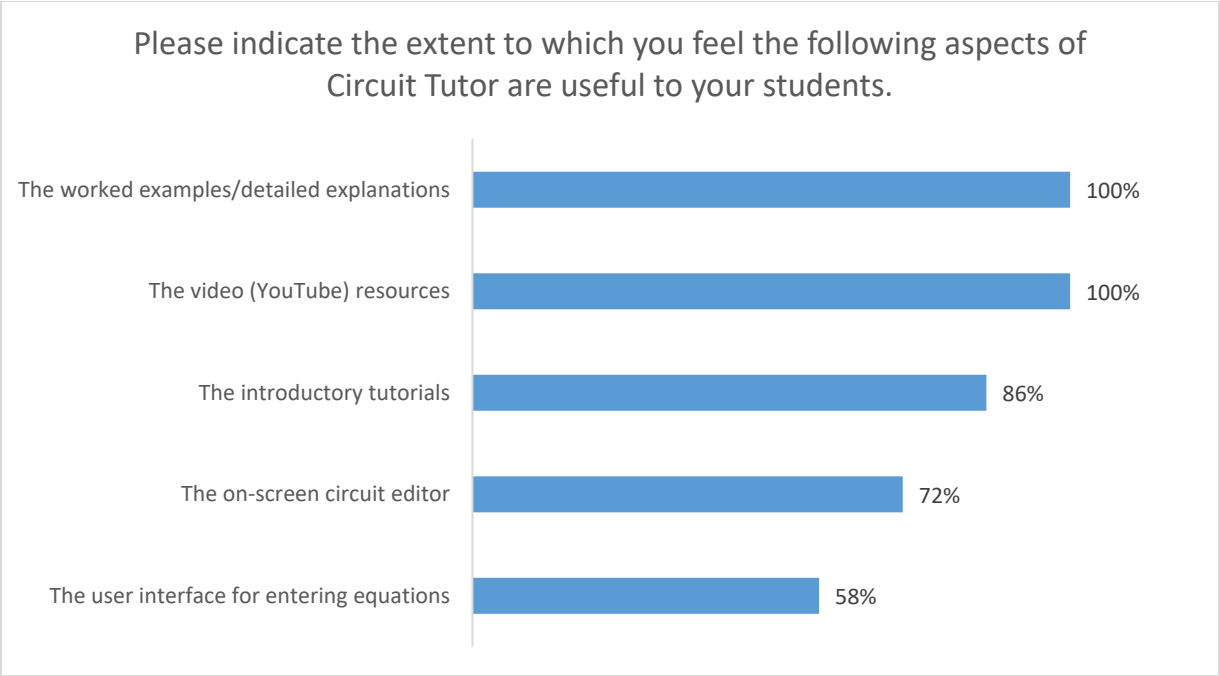
The instructor survey data presented below was collected in the spring 2021 semester. Generally, the instructors had favorable teaching experiences using Circuit Tutor. Overall, 57% (4of 7) of instructors reported that Circuit Tutor made teaching their classes somewhat more effective and 57% (4/7) reported that Circuit Tutor made it somewhat easier or much easier to teach their classes compared to other types of homework systems for that class.

	SPRING 2021 (N=7)
Circuit Tutor makes teaching my class **"Somewhat more effective"** for me than when I used a different type of homework system in this class.	57%
Circuit Tutor makes teaching my class **"Somewhat easier" or "much easier"** for me than when I used a different type of homework system in this class.	57%

4. HOW DID INSTRUCTORS PERCEIVE THEIR STUDENTS TO EXPEIIENCE 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 Circuit Tutor when compared to the previously used homework system in his/her class. Slightly less than half of the instructors (43%; 3/7) reported that their students were "somewhat more motivated" or "much more motivated" to study linear circuit analysis when using Circuit Tutor compared to the other homework system.

Instructors were also asked about the extent to which they felt the following aspects of Circuit Tutor were useful to their students. As shown below, all instructors (100%) perceived the worked examples/detailed explanations and video tutorials were useful to their students. This was also supported by the student quantitative and qualitative survey data. As shown below, the next highest features of Circuit Tutor that instructors perceived useful to their students were the introductory tutorials (86%; 6/7) and on-screen circuit editor (72%; 5/7).



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

STUDENTS

Students were asked some open-ended questions in their end of the course surveys in the fall 2020 and spring 2021 semesters, providing a more nuanced understanding of their experiences with using Circuit Tutor. 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?

Some of the major themes that emerged in the first question were:

- Worked out examples/detailed explanations
- Practice/repetition
- Easy to insert and edit equations
- Sound effects/visualization/interactive effects
- Easy to insert and edit equations
- Tutorial videos

> I like the fact that Circuit Tutor takes you step by step on how to solve circuit problems and guides you on how to think through problems. Textbook problems only ask for a final answer and don't have as much clarity in solving problems as Circuit Tutor. I did like many of the interactive elements of Circuit such as the loop/mesh analysis sections and the resistor/circuit simplifications sections. I think that both of these and many others were able to help me understand the concepts a lot better than if I had used a textbook or some other learning material so good job with that!

Theme	Illustrative Comments
Worked out examples and detailed explanations of solutions (N=44)	"Having worked examples available and trying new problems until getting it right." "The games and the worked examples were very useful for understand the concepts presented." "I liked how it explained how to do the problem after. Every explanation was very detailed and helped me understand it for the next problem."
Sound effects and visualization/interactive effects (N=30)	"The sounds are encouraging and I like the interactive parts of solving a circuit." "I really enjoyed the sound effects and the cheering. After a hard problem nothing felt better than having those virtual people cheer me on." "Definitely the sound bites when I finish a problem it gives me instant gratification and motivates me to keep going. It's a good reward system." "The color coding was also useful to visualize what was happening in the circuits."
Practice/Repetitiveness (N=29)	"I liked the repetition of important steps required to complete the games. Constantly entering equations in nodal/mesh analysis made it easy to learn. I also liked how important concepts were introduced in the easy levels, and expanded upon on the harder levels. "I liked the setup of Circuit Tutor because it gave me enough practice problems so that I would actually understand the content when I was finished with the assignment. " "…With repeated practice I was able to complete problems just by hand for up the upcoming exams/quizzes, and I credit that to the practice with circuit tutor."
Easy to insert and edit equations (N=17)	"It is easy to insert and edit equations and the circuit visualization and editing are easy to use." "Being able to see all the equations before me to select from because I never felt lost or unsure of what my goal was at each step." "I also like the equation editor because it helped me understand how to build the equations and how they actually worked, which also really helped with sign conventions." "I liked the drag and drop system because it gave me a more clear idea of the equations that we were expected to set up. The

	color coding was also useful to visualize what was happening in the circuits." "I liked how I could give up and see where I went wrong and how to do it right. Also the drag and drop equations made it easier for me rather than remembering all the equations.
Tutorial videos (N=18)	"The tutorial videos went a long way for helping me understand how to do each difficulty level of the assignments. "I loved the progression system of easy to hard levels and I loved that there were instructional videos for each level. "I think including the youtube videos explaining how to operate circuit tutor should be first and foremost before attempting the game."

These themes with some examples of illustrative quotes capturing these themes are included below. All data were gathered through the open-ended survey questions.

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

Students were also asked about recommendations they would make to improve Circuit Tutor. Some of the most prevalent themes that emerged included:

- Updating the UI/improving the layout
- Increasing the number of attempts on some of the more difficult problems
- Making the tutorials less wordy and more concise

Some examples of illustrative quotes capturing these themes are included below. All data were gathered through the open-ended survey questions.

I did like many of the interactive elements of Circuit such as the loop/mesh analysis sections and the resistor/circuit simplifications sections.

The structure provided when first learning is very helpful. Instead of having to deal with all the steps to each problem at first, I appreciated the guidance provided in the low levels and then with increasing difficulty we are left to finish the entire problem alone. The visuals were also extremely helpful. Finally, the videos were an absolute life saver for the later assignments that were more difficult.

Theme	Illustrative Comments
Update UI/improve layout (N=26)	"Improve layout (viewing restrictions, inconsistency in decimals required and decimals allowed) "Rework the user interface to be cleaner and more refined. Certain actions also caused the program to freeze or slow down briefly, like dragging equation terms or transitioning between dialog boxes. "The user-interface needs a very serious update. With the way it currently stands, a lot of the homework would take many extra hours just based on small mistakes with the interface.
Increase number of attempts (N=24)	"Perhaps allowing more attempts before restarting a problem because there have been times when I had to restart an entire problem for a simple mistake." "I would definitely up the number of attempts on some of the more longer or more difficult problems, as it is irritating to restart a problem from scratch when you are only unsure of one aspect of the question. On shorter problems its not really an issue, however on the big analysis questions I think there should be more forgiveness." "When you first start a problem, you should be given X amount of attempts for the problem before you start to lose the credit. After that, if Circuit Tutor knows that you've been struggling on a set/problem and it's your fourth attempt I believe it should up the number of errors allowed."
Make tutorials more brief (N=21)	"The text for the tutorials were way too lengthy and hard to keep my focus on." "Some of the Tutorial steps before the actual games are quite lengthy and go into extreme detail into concepts that were either not covered in class or are not needed during the games." "The tutorials before the games were very thorough and full of good information, but I think it would be helpful if there was an option to go through a modified summarized version of the tutorial. They were just so long that sometimes I didn't have time and I had to click through a lot of it." "The explanations for certain problems seemed more complicated or wordy than they had to be."

Some other themes that emerged at lower frequencies included:

- Making Circuit Tutor accessible for MacBook users
- Working out some of the bugs to avoid the program crashing
- Decreasing the volume on the sound

Some example quotes that support that data are listed below:

> "That the software somewhere near in the future can be used on Mac too, because a lot of my classmates and me have issues to run the program because we use Macs."

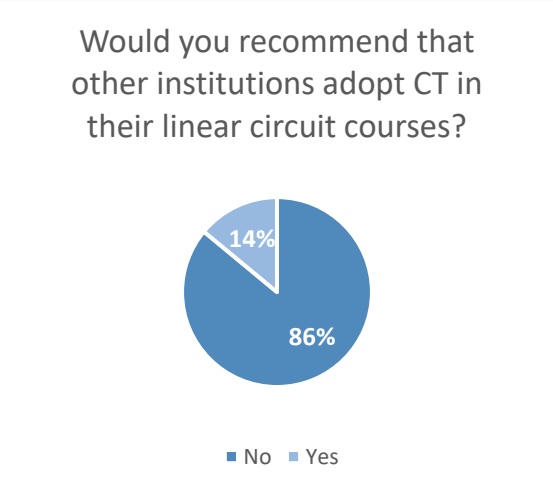
> "Circuit tutor would crash in the middle of a problem and was very sensitive with how answers were put in. Sometimes it would mark me wrong, but the correct answers were the same as what I put in."

> "The circuit tutor program, especially towards the end of the semester, started running more and more slowly and would crash more often. There were a few times were it would freeze while I was in the middle of a problem and I would have to start over."

> "I would recommend for the default volume of sound effects to be drastically reduced…"

> "I like the instant feedback and the explanations for the problems I did wrong. I also like the sound effects after finishing a level but it can be a bit jarring if you forgot you had your volume really high. It scared me the first few times. Maybe softer sounds that are not people shouting?

INSTRUCTORS



Overall, the instructors were satisfied with their experiences using Circuit Tutor as shown through the high percentages of instructors who would recommend Circuit Tutor to other instructors (86%; 6/7). Further, 100% of the instructors reported having adequate administrated support (e.g., enrolling students, crating TA accounts, setting up assignments, downloading grades, monitoring progress, etc.)

The faculty reported strengths and "areas that need improvement" based on their experiences with Circuit Tutor in open-ended survey questions. Some of the results are highlighted below.

CIRCUIT TUTOR STRENGTHS

Some of the instructor comments included the way in which CT helped students achieve a deeper conceptual understanding of how circuits work, helped students practice visually, provided immediate

feedback and support, and forces students to use the technique required to solve specific problems. Some illustrative quotes to support these data are below:

> "Helps students achieve a deeper conceptual understanding of how electric circuits work."
>
> "Circuit Tutor is an effective means of requiring students to submit homework and records of submissions are readily available."
>
> "Ability for students to practice visually."
>
> "Immediate feedback and support to the students. Encouragement throughout the process. Abundant resources to help with learning. Variety and number of problems to prevent academic integrity violations. The step-by-step approach to each problem to encourage learning."
>
> "It forces the students to use the technique required to solve specific problems, unlike other tools where the students can apply any method to solve a circuit problem without the instructor knowing."

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, making the tutorials shorter/less complicated, and modifying the way in which the various mastery levels are labeled, adding more application type problems and Op-Amp circuits as a topic area. Some illustrative quotes that emerged from the open-ended survey are provided below:

> "Sometimes students have issues with compatibility of the software with the personal computers."
>
> "The interface problems cause students a lot of grief."
>
> "User interface for equations is the most difficult, lots of errors.
>
> "I believe Circuit Tutor has many advantages with respect to Mastering Engineering. The main advantage is that the students has a tremendous amount of help with online videos and tutorials on Circuit Tutor, while Mastering Engineering only has the textbook as a reference. I would not change anything on the amount and type of examples and the explanations. The interface entering equations is a bit complicated at the beginning, but it is relatively easy to use it once one is familiar with the tool."
>
> "…The interface is outdated. The students grew up with technology and the system looks very outdated to them. An update to the interface would make the software feel more relevant to the students and increase their connection to it. I think the content is fantastic - the biggest "bang for your buck" change would simply be the look of the interface."

"The number and variety of available resources to help the students are fantastic (videos, tutorials, examples). The tutorials are sometimes long and over-complicate the understanding. I really like that the option to make the tutorials optional is now available."

" The step-by-step approach to learning is excellent, but I would like to see less of it in the Mastery Level - I'm finding students are using the scaffolding as a crutch and sometimes have a hard time outside of the software when given a problem to solve. The interface is outdated and I get this comment from students regularly."

"I am not sure it is a good idea to have a clear division between beginning, intermediate, and mastery levels. I would probably label those as level 1, 2, 3 or another way. Extending the natural and step response of RLC circuits would be useful in our classes."

"More application type problems (the existing problems can be "re-framed" with an application and/or user). This would be especially useful at Mastery level."

"Adding Op-Amp circuits would a topic that would of interest to us. The instructor of the Electronics I course (for which electric circuits is a prerequisite) has impressed upon us the need to cover intro to Op-Amps. This topic is covered extensively on the Electronics I course."

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS:

Document review and surveys confirmed that all lead instructors successfully implemented Circuit Tutor system within their classrooms. Taken together across both semesters, 92% (91% in the fall; 93% in of the students across all universities somewhat agreed or strongly agreed that Circuit Tutor to be useful in supporting their course learning and 73% agreed to the same extent that all of the features were useful in their learning. The instructor findings showed that 86% of them would recommend that other institutions use Circuit Tutor. More than half of the instructors reported that Circuit Tutor was more a more effective method to teach their courses (57%) and that Circuit Tutor made teaching their class easier (57%) Overall, both students and instructors were satisfied with Circuit Tutor and they also gave constructive feedback on ways to improve it.

STUDENT AND INSTRUCTOR RECOMMENDATIONS:

Data from the student and instructor open-ended survey questions provided insights into how the Circuit Tutor program could be improved for future use. Both suggested that the interface could be updated. In addition, students recommended more allowable attempts for solving difficult programs, fewer words in the tutorial descriptions, accessibility for Macs, work out computer "bugs" to decrease program crashing, and decreasing the sound volume. Instructors also suggested shortening the tutorials, modifying the way in which mastery levels are labeled, and adding more application type problems and Op-Amp circuits.