

# Impact of a Step-Based Tutoring System on Student Learning at The University of Texas at El Paso

## Abstract

In this paper we describe the historic background of how the introductory course of Electric Circuits I has been taught, and the different modifications this course has undergone for the past seven years. We describe preliminary results of a new step-based method on student learning which has been applied at the University of Texas at El Paso (UTEP) to improve students' understanding of the topics covered in this course, and describe the step-based tutoring System, dubbed Circuit Tutor, developed by researchers at the UTEP. The results indicate Circuit Tutor platform can be used as a self-learning tool according to survey answers from students and the increasing passing rate in the Circuits I course.

## Keywords

Electric Circuits, Step-based tutoring System, Circuit Analysis

## 1. Introduction

One of the most widely taught courses to undergraduate students in electrical engineering, and students to other engineering disciplines (also called “electrical circuits for non-believers” by some instructors) is the first course of electrical circuit analysis (or second course on electric circuits if the students has taken an introductory course on electrical engineering). This course has been taught traditionally in two sections of approximately 35 students every semester, and usually by two different instructors. This course is also offered during the summer in one section with similar student enrollment as the regular semester. The statistics presented here are only from the regular semester, as the summer enrollment usually has more variability due to both; the number of students and students who have taken the course before during previous regular semesters, therefore, in general these students have previous knowledge of circuits analysis techniques.

Different tools have been used to improve the passing rate in the Circuits course; for example, Mastering Engineering (ME). ME is a web-based tool which is a companion tool that accompanies a popular book on circuit analysis [1] and it provides problems on topics strictly related to this textbook. This tool is used to promote and enhance student learning in an any-time, any-where setting allowing the student to work and even collaborate with other students inside and outside the classroom. They also help reduce faculty lead time in important tasks that matter to students like immediate feedback on homework assignments.

In ME, most problems are multiple choice-type problems, and the student must choose the right answer after some number of trials (this the default setting) before losing all the points on a specific problem. The advantage of using this web-based tool is that the homework is graded automatically and give immediate feedback to the student, as opposed to taking one or two weeks for the

homework to be graded and handed back to the students. A step-based interactive learning and automated grading system, coined Circuit Tutor, was developed to promote effective learning on main topics of electric circuit analysis [2] and has been in use since Fall 2012. This tool started being used at the University of Texas at El Paso since Fall 2018.

The system is based on a program that generates electric circuit problems with random topologies, and detailed solutions. A GUI has been implemented to allow the student to easily input array elements in the online system of equations and the user is allowed to place the reference (ground) wherever desired. A difference between both tools is the color coding and labeling of branches and node voltages (in the Node-Voltage games) to allow an easy identification of all the branches connects to essential nodes. Unlike Circuit Tutor, ME color-codes the unknown parameters the student is required to solve for, but it does not use any other color scheme to highlight, for example nodes, meshes, or equations. Fig. 1 presents an example on how the node colors change depending on the KCL equation in Circuit Tutor.

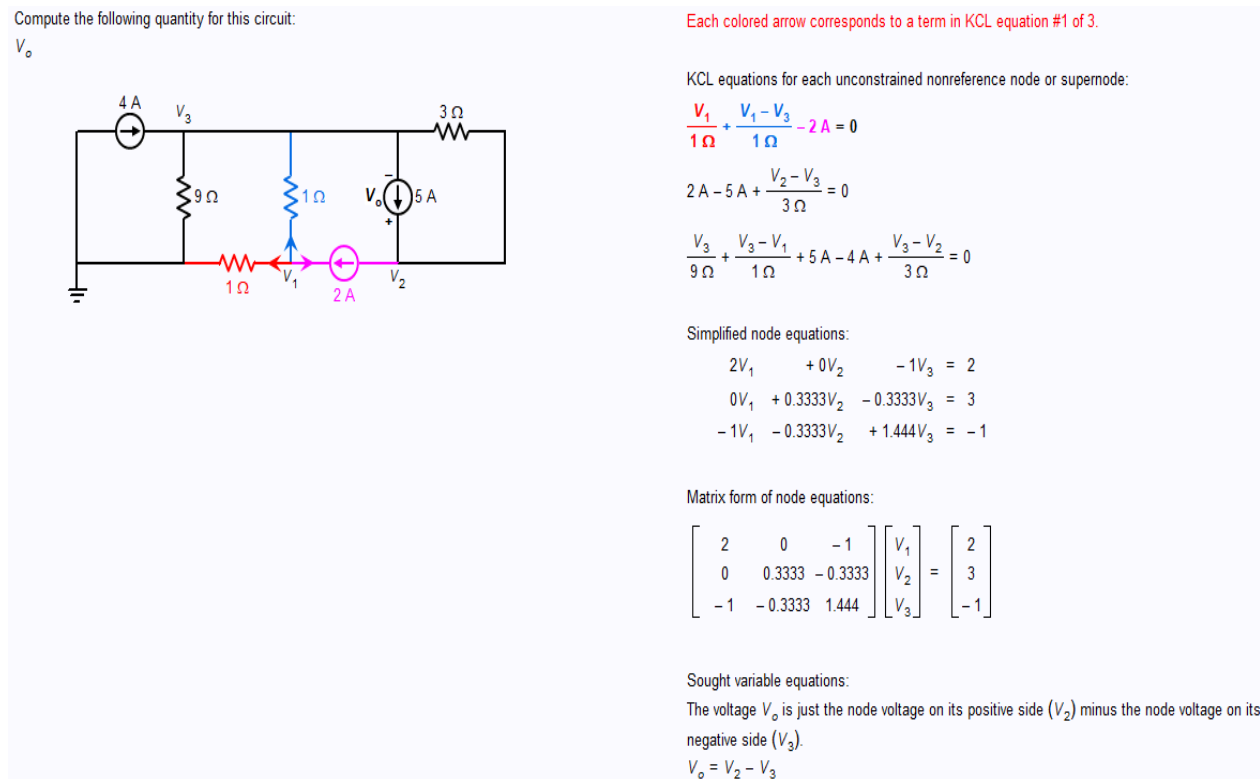


Fig. 1. Random example solved of "DC Node Equations", first KCL equation colored corresponding to the  $V_1$  Node. Once all the equations are presented, each component of it will be colored as the example.

Another feature is that Circuit Tutor offers examples and games for various levels of difficulty (Easy, Medium, Hard and Mastery) of each tutorial. This is also an advantage because using these levels, the user can practice and improve in circuit analysis. Figure 1 is an example of an “Easy” example of a DC Node Equation tutorial. One of the most remarkable features in Circuit Tutor is the YouTube channel. If the user has questions related to a topic, the “Video Help Channel” button would open a new YouTube window, where the available material addresses an explanation on the topic and how to use the Circuit Tutor tool to solve an example problem. Fig. 2 presents the YouTube help videos once the “Video Help Channel” button has been clicked.

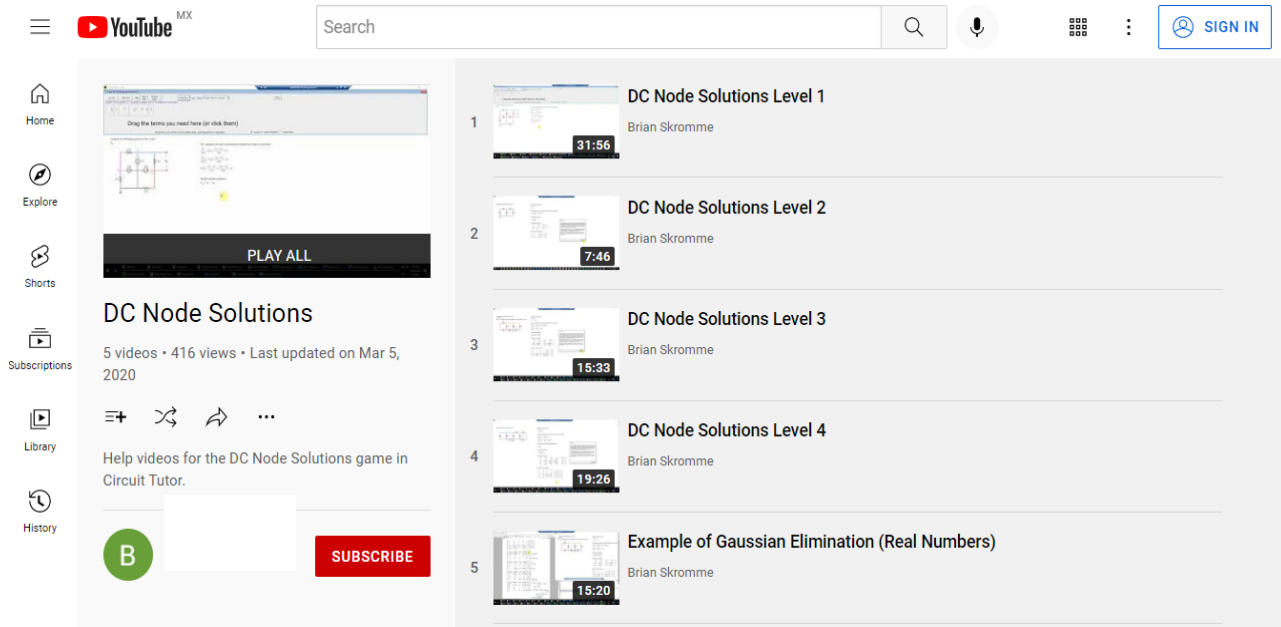


Fig. 2. Video Help Channel of Circuit Tutor. DC Node Solutions tutorial

In comparison to ME, Circuit Tutor is free to students, and it is available to instructors to use in their courses. Access is granted by contacting Dr. Brian Skromme at his Arizona State University e-mail. To UTEP standards, the enrollment in the course is slightly larger than other courses offered by the department, so to be able to give the students fast feedback in their progress and their scores as soon as possible on the assignments, there is a need for the use of automated grading tools like Circuit Tutor.

## 2. Contents of the Course

Traditionally, the course is taught by different instructors every semester, except on a few occasions in the last six years both sections have been taught by the same instructor. The topics covered include DC and AC circuit analysis (but not Bode, transfer functions, nor Laplace transformations topics, which are covered in the Electric Circuits II course) from the textbooks most often used in the past five years, the one by J. W. Nilsson and S. A. Riedel [1]. Another textbook used less often is the one by Ulaby and Maharbiz [2]. The later book includes examples on the use of modern SPICE packages like Multisim, which is a GUI tool that makes both circuit design and analysis more intuitive for the student. In general, the topics covered by the different instructors include a)

Overview of Circuit Analysis and Terminology b) Simple Resistive Circuits c) Kirchoff’s Voltage Law (KVL) and Kirchoff’s Current Law (KCL) d) Thévenin/Norton Equivalents e) Operational Amplifier Circuits f) Inductor and Capacitors Circuits g) Sinusoidal Analysis and Impedance Concepts h) Phasor Analysis and Power of AC circuits. Most instructors divide the topics into two main groups; DC circuit analysis and AC circuit analysis, as the analysis methods covered in DC analysis are typically the same methods covered in AC analysis. Also, the tools available to the students at the Laboratories, or available for the students to download and install into their own computers, are Multisim and MATLAB, and on some occasion projects (“Mini Labs”) are assigned where the students need to build circuits and take measurements using the Analog Discovery instrument from Diligent, to measure the natural response of RC circuits, for example.

The electric circuits course has been deemed one of the courses that cause a high attrition rate at many universities and therefore it is one of the courses that receives the most attention for improving student passing rate [3-5]. At UTEP the passing rate for this course is low compared to other courses offered by the department. The passing rates per semester are shown in Fig. 3. There is a need for a methodology to improve passing rate and student understanding of the topics, and therefore improvement of passing rates. The statistics department has implemented measures to improve the passing rates which include increasing the availability of the instructor and teaching assistants.

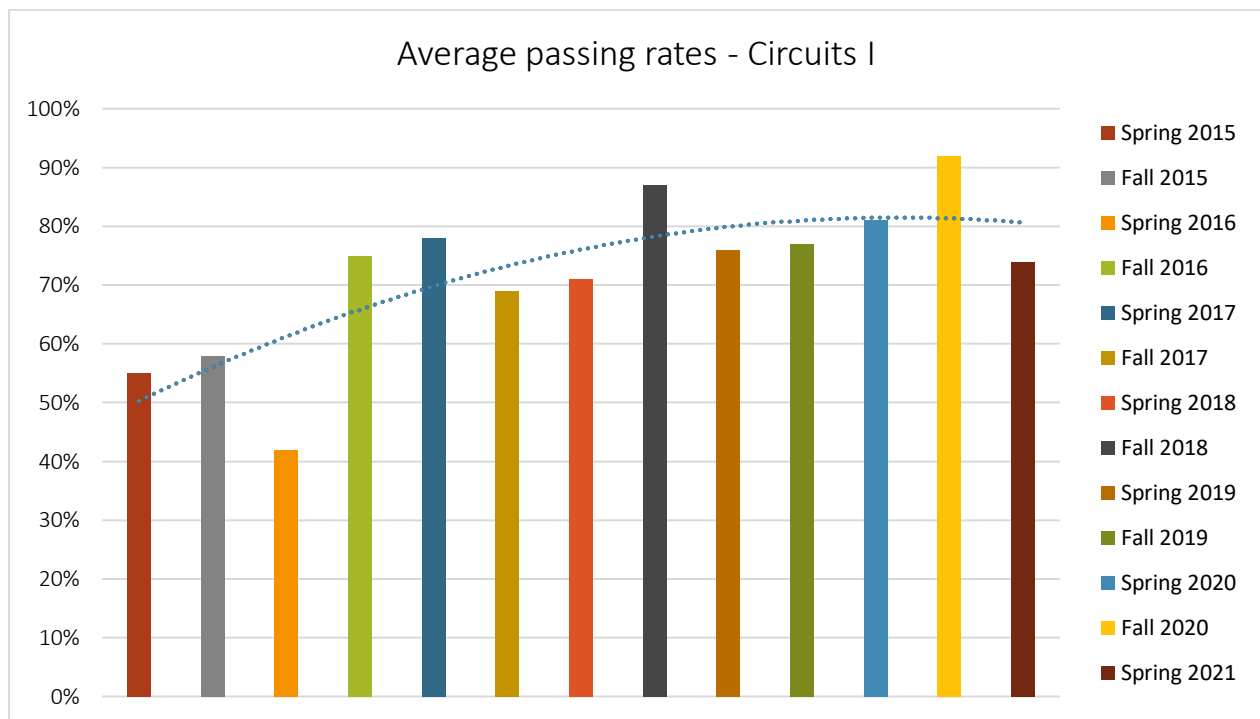


Fig. 3. Average percentage of passing rates of the two sections offered during regular semesters over the most recent seven years. The 2<sup>nd</sup> order trendline shows how the passing rate fluctuates ( $R^2=0.609$ ).

We have mentioned that the Circuits Tutor tool has been extensively used since 2018. The chart presents the semesters of Fall 2018 to Spring 2021, where the passing rate exceeded the 75% of average pass, which represents a good result in comparison with past years. The course was taught online from March 2020 (2<sup>nd</sup> part of Spring Semester) to Spring 2021 because of the pandemic. On the semester of Spring of 2021, this rate decreased to 74%. A theory for this decrease could be because the semester was completely online because of the COVID19, the students were not used to online classes for courses like Circuits I, where most of the students on that semester were Sophomore and Junior levels. In comparison to Fall 2020, most of the students (60% of the class) were Junior and Senior levels, which we can conclude they were used to working in online environments.

### **3. Web-based Assignments**

Traditionally, instructors for this course have used the Mastering Engineering tool by Pearson to assign homework when the book by Nilsson and Riedel, which is a popular tool for assigning online homework [6,7]. Some instructors have also used the textbook by zyBooks, Circuits. A new web-based tool which we started using since 2018 is the Circuit Tutor [8]. This is a CAD tutoring system being developed with the objective to complement (and replace) the conventional assignment system. The software provides immediate feedback to the student at every step in the process of solving a problem. It can generate new problems, should the student decide to give up (which is one of the options available to the student) on the current problem. This gives the student the opportunity of reviewing similar problems on the same topic by a mere click of a button. The software accepts different correct solutions from the user, and it is not constrained to a fixed format [9,10]. A major feature that differentiates this software from other ones is that the student is allowed to “compose” the solution equation directly on the computer screen and receive immediate feedback about the correctness of the student’s solution. The methodology followed to generate is based on a three-step algorithm described in [11].

The detailed outline of the topics covered in the course (since Fall 2018) are described in the first column of Table 1. The topics covered by Circuit Tutor are described in the second column (as of Spring 2020). Most of the topics included in this course are included in Circuit Tutor, and therefore it well suited for assigning homework on most of the topics (other topics are assigned on Mastering Engineering, which is the companion software to the textbook).

A couple of key features of the Circuit Tutor on new releases (since Spring 2019) is that there is available numerous (more than 70 videos) available on YouTube, which students are recommended to review, to get acquainted with the tool before starting to solve homework [12]. Another important feature of a recent version of the software is that the package saves the history of correct and incorrect steps the student takes to solve the problem and is available to the student for reviewing.

Table 1. General topics covered in Electric Circuits I in Chronological Order (left column), and List of Circuit Tutor Topics as They Appear on The Web Interface (right column)

| Topics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Circuit Tutor                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b><u>DC Circuit Analysis</u></b></p> <ol style="list-style-type: none"> <li>1. Independent/Dependent Sources</li> <li>2. Kirchhoff's Current and Voltage Laws</li> <li>3. Resistors in Series and Parallel</li> <li>4. Voltage and Current Division</li> <li>5. Delta-to-Wye Equivalent Circuits</li> <li>6. Node-Voltage and Mesh-Current Methods</li> <li>7. Source Transformations</li> <li>8. Thévenin and Norton Equivalents</li> <li>9. Maximum Power Transfer</li> <li>10. Superposition</li> <li>11. Operational Amplifier Circuits</li> <li>12. Inductance and Capacitance</li> </ol> <p><b><u>AC Circuit Analysis</u></b></p> <ol style="list-style-type: none"> <li>13. Impedance and Reactance</li> <li>14. Kirchhoff's Laws</li> <li>15. Series, Parallel, Delta-to-Wye Simplifications</li> <li>16. Source Transformations and Thévenin-Norton</li> <li>17. Node-Voltage and Mesh-Current Methods</li> <li>18. The Transformers</li> <li>19. Instantaneous Power</li> <li>20. Power Factor</li> <li>21. The RMS Value and Power Calculations</li> <li>22. Complex, Average, and Reactive Power</li> <li>23. Maximum Power Transfer</li> </ol> | <p><b><u>DC Circuit Analysis</u></b></p> <p>Series/Parallel<br/> DC Single Node-Pair/Single Loop<br/> Series/Parallel with Terminals<br/> Resistor Simplification<br/> DC Node Equations<br/> DC Node Solutions<br/> DC Mesh Equations<br/> DC Mesh Solutions<br/> DC Superposition<br/> DC Source Transformations<br/> DC Thévenin/Norton Equivalents Circuits<br/> L/C Simplifications</p> <p><b><u>AC Circuit Analysis</u></b></p> <p>Impedance Simplification<br/> AC Node Equations<br/> AC Node Solutions<br/> AC Mesh Equations<br/> AC Mesh Solutions<br/> AC Analysis</p> <p>Bode Plots*<br/> Laplace Transforms*<br/> Inverse Laplace Transforms*</p> |

\* Topics to be covered in Electric Circuits II.

#### 4. Student Usage and Evaluations

Prior to Spring 2019 the different instructors for this course used exclusively the Mastering Engineering tool to assign homework. Circuit tutor has been extensively used in UTEP since 2018. To assess student satisfaction with this software, brief surveys are administered by an independent evaluator at the end of every semester. Notice that this survey is not a requirement for the students, so each year from 2019, the number of participating population changes. Table II describes comments from the student satisfaction surveys on two different semesters (and therefore two different versions of Circuit Tutor).

Table 2. Sample of Verbatim Students Comments on the Software

| Semester    | Comments                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fall 2019   | Process Support Learning <ul style="list-style-type: none"> <li>• It helped me perfect my skills in circuit simplifications</li> <li>• (The) practice problems seriously helped my understanding of concepts</li> <li>• I like that it helped (me) understand the concepts that are described in the book</li> <li>• This system was extremely helpful (and helped me) understand the basics of circuits and help me improve throughout the class</li> </ul>                                                                                                                                                                                                                 |
|             | Videos <ul style="list-style-type: none"> <li>• What I like best was that it had video explanations for every problem and there you could give up and the way it should be done</li> <li>• I like the help videos because it was easy to follow and understand</li> <li>• The helpful videos linked to the problem</li> </ul>                                                                                                                                                                                                                                                                                                                                                |
| Spring 2020 | Process Support Learning <ul style="list-style-type: none"> <li>• I liked that you have to work each part of the problem, so it is good for us to learn. I also really like the solved problems because they serve as a useful guide</li> <li>• I liked that CT (Circuit Tutor) explained all the necessary steps involved to arise to the solution and that it explained step-by-step, in detail.</li> <li>• I liked the feedback given as to how I might have done the problem incorrectly or tips to remember provided in the reading material</li> <li>• I enjoyed how the software takes you step by step! It is very useful when trying to learn the topics</li> </ul> |

Changes in the software produce positive comments from the students for the two consecutive semesters (Fall 2020 and Spring 2021). For example, increasing the number of YouTube videos features allows students to get a better understanding of how to use the software. Also, students like a new feature which allows them to backtrack the solutions and provide alternative solutions as well. In Fig. 4, a satisfaction survey is presented. On this study, 13 over 38 students participated on Fall 2019 (33%), 16 over 30 students on Spring 2020 (53%) and 14 of 28 students on Fall 2020 (50%). In semester Spring 2021, this survey was also implemented, where the entire population (31 over 33 students) participated, representing 94% of participation.

The chart presents the results where the students responded agree to the corresponding affirmation. Notice on Spring 2020, more than 50% of the students that participated in the survey agreed on each of the affirmations. One of the main purposes of this tool is to help students to develop skills on circuits analysis improving the current methods as we had mentioned before. Fig. 5 presents the general opinion of the students from Spring 2021 about the methods used in CT in contrast to the conventional approaches.

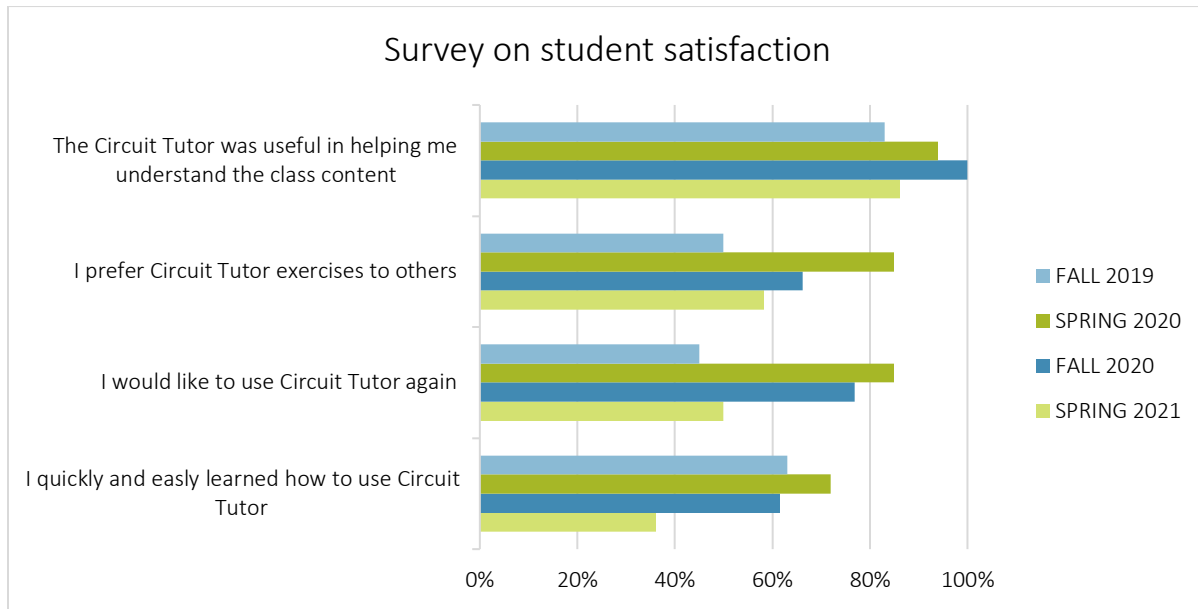


Fig. 4. Responses to survey on student satisfaction for Fall 2019 to Spring 2021. Percentage values correspond to students who responded “agree” or “strongly agree” on the survey.

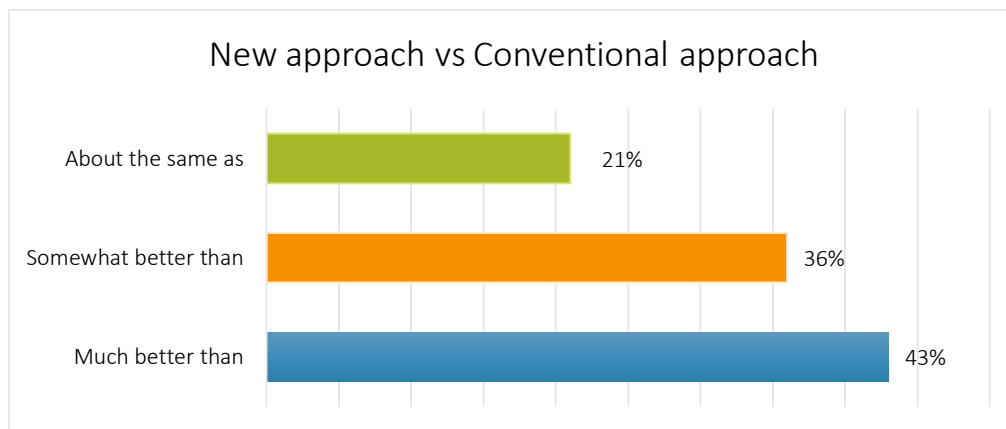
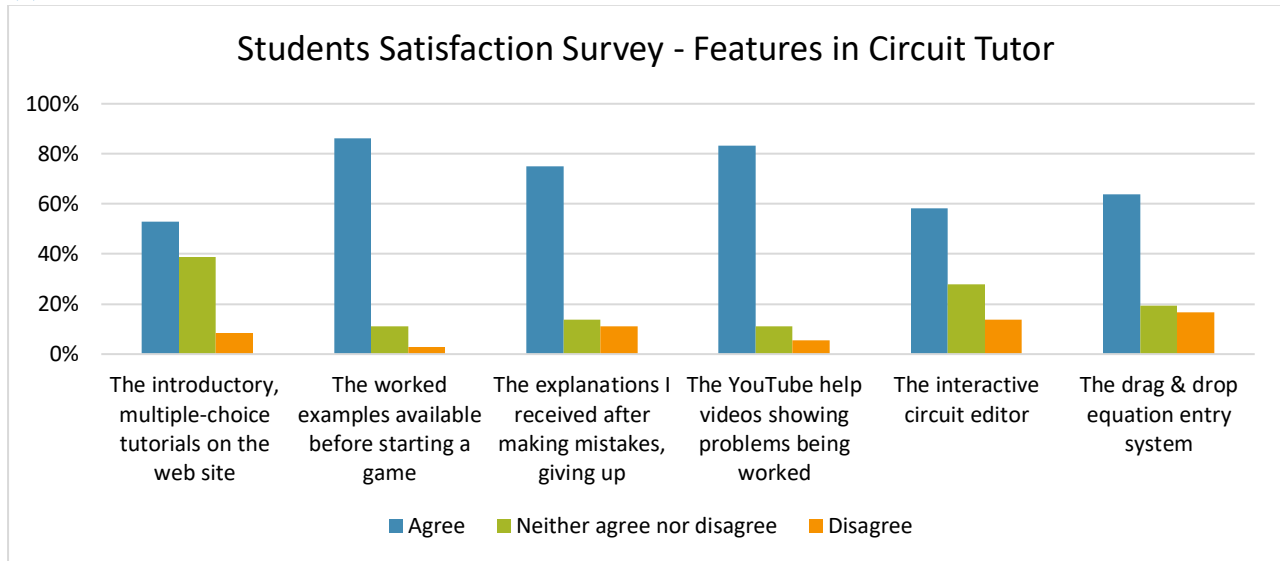


Figure 5. Innovative approach vs. conventional approach. Close to 80% of this population considers that this tool is better than the conventional methods, while the remaining population concluded that it is the same as the conventional approach.

It can be observed that almost 80% of the surveyed think this innovative approach is better than the conventional. To achieve the goal of this tool’s improvement, is to consider the user’s opinion, which means implementing different surveys to understand what the student thinks in comparison to another methods is an important detail to consider. Showing worked examples before start playing, coloring nodes and mesh currents to distinguish each part of the equation and have various levels of difficulty are some features the platform have, which have been discussed before on this paper. Fig. 6 presents the students satisfaction survey from the Spring 2021 semester.



(a)



(b)

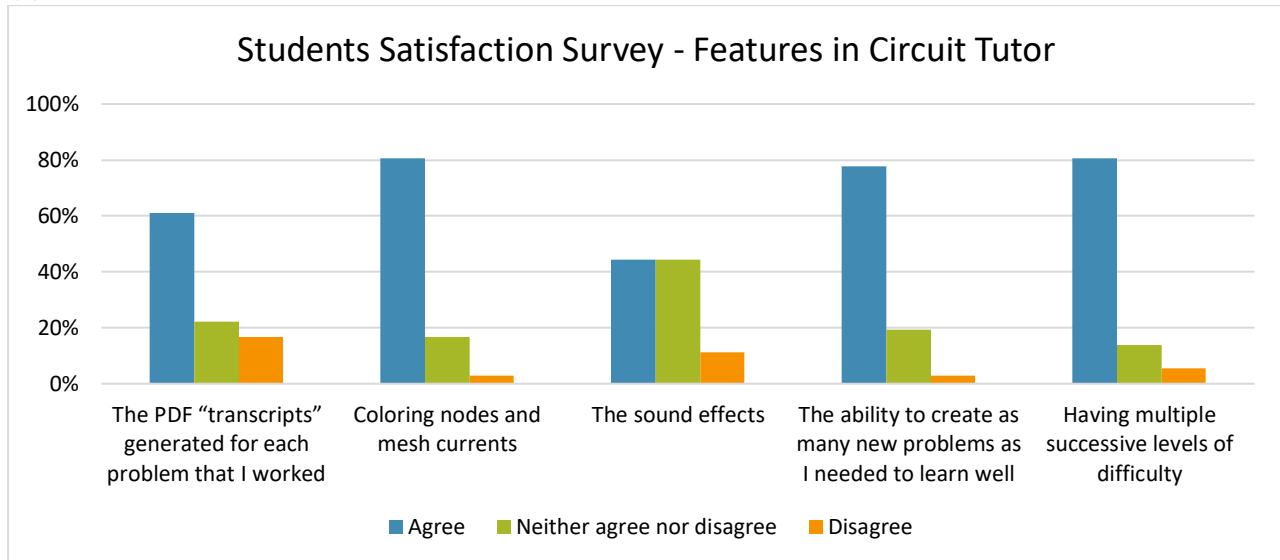


Fig. 6. Students' satisfaction survey: features of Circuit Tutor. Percentage values correspond to students who responded "agree" or "strongly agree" on the survey.

According with 31 of 33 students, one of the most helpful features is to show worked examples before starting to solve problem, while the sound effects in problems resolution do not represent a useful feature of the platform. As a conclusion of the student responses, most of the features in Circuit Tutor are useful to learn or to motivate to learn the material from Circuits course.

## 5. Conclusions

A step-based tutorial software has been incorporated into the Electric Circuits I course at the UTEP with positive passing rate results. The Circuit Tutor software includes all the topics required for

students to practice problems in different difficulties from most of the topics covered in our intro course on Electric Circuits. Preliminary survey responses from two consecutive years shows that the software helps students to better understand the methods used for analysis of DC and AC circuits. Because their responses have been favorable as seen before, this shows that Circuit Tutor could be used as supporting tool for teaching and a student self-learning circuit analysis platform. The passing rate trend indicates this could continue improving over the next semesters. However, consider developing teaching strategies for events such as the COVID19 pandemic is needed to keep obtaining acceptable passing rates. Some topics covered in the course are still not part of Circuit Tutor and some, like Bode and Laplace are in place, but these are part of the Electric Circuits II course.

## 6. Acknowledgments

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