Interactive Electrical Circuit Tutoring Tool – *e*Tutor

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Abstract – Current methods of educational delivery in the field of basic electrical circuits are highly dependent on theoretical, analytical and applied approaches. Such methods are almost entirely delivered face-to-face in classroom and lab settings with minimum or lack of individualized delivery or assessment practices. However, the increasing number of students with different learning styles makes it harder for students to grasp the basic circuit analysis concepts. In this paper, we introduce an interactive individualized electrical circuits tutoring (*e*Tutor) tool that helps students individually learn key concepts in electrical circuits analysis methods. This tool guides the student through a step-by-step analysis of common electrical circuit problems. In each step, the tool prompts the student to enter a formula that best describes the current step in the analysis method. Then, it responds with a personalized feedback that is dependant on the user's formula. Through the feedback process, the tool targets all lexical and analytical errors in the user input. The tool compiles a list of errors and warnings messages that are reported back to the student. Trials and interactive elaboration on errors allow the student to understand better the targeted concept in circuit analysis. The modular and template based design for the tool allows adding and modifying key problems by the instructor. In this paper, we will discuss the basic design of the *e*Tutor, and report on an assessment study on the effect of using the *e*Tutor in the introductory circuit analysis class at University of Central Florida. The study shows promising results with clear performance improvement when *e*Tutor was utilized and compare to students who didn't use the tool.

*Keywords: e*Tutor, Electrical Circuits, Tutoring, Interactive, Tool.

I. Introduction

According to University of Central Florida's (UCF) course catalog[UCF, 7], design experiences in Electrical Engineering (EE) first start with a circuit analysis course. For other non-EE majors, at least one introductory course on electrical circuits is required in the program. The main objective of this paper is to present a fully structured methodology to tutor EE and non-EE major students to formulate effective strategies that help them learn, retain and apply different concepts of circuit analysis.

The proposed approach is to present a unique interactive learning style using materials that combine graphics with personalized feedback that will allow students to understand and to correct their mistakes without the instructor being present. This proposed approach will be beneficial for large class sizes, where personalized student-instructor interactions are difficult. Because each student learns at his/her own pace, it is difficult for a professor to evaluate effectively the comprehension level of each student. Highly personalized feedback to students' time may result in a delay of class material coverage or learning of the next level of electrical circuits without fully understanding the basics of circuit analysis. With the *e*Tutor tool, students will be able to solve problems and obtain the same type of

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specific feedback they would receive from the class instructor. An effective feature of the *e*Tutor is that it is highly interactive — providing personalized feedback that points to specific errors made by the students. The *e*Tutor will not only inform the student if his input to a question was right or wrong, it will also specify what type of error was made in the symbolic equation. The rest of this paper is organized as follows: In Section II, we discuss the motivation for designing our tool, where in Section III, the system architecture for the tool is discussed. In Section IV, experiment design for testing the system's effectiveness is presented. Section V contains the results collected from our experiments. We then list the related work in Section VI and present conclusion in Section VII.

II. MOTIVATION

Circuit analysis and electric circuit theory are vital and important parts of electrical engineering curriculum in schools in the United States and around the world. In fact, introductory circuit analysis courses are now being taught as a core course for all engineering students within the first few semesters. For students who continue to pursue their education in electrical engineering, they must take additional course(s) in electric circuit theory, where the material is often dry and can be difficult for to absorb and understand easily. Moreover, students who suffer from a lack of understanding of fundamental circuit analysis also have difficulty in understanding subsequent electrical engineering courses. One of the causes of these problems is the lack of appropriate teaching tools and methods. More specifically, we believe the lack of interactive feedback when students work on circuit analysis problems with traditional tools makes it difficult for them to understand interrelationships between variables and the underlying mathematics associated with the different components of circuit diagrams. Typically, these tools are simply pencil and paper or a whiteboard, which provide no interactive feedback and cannot assist students during problem solving. Other tools, such as circuit analysis software packages, do exist, but their interfaces are difficult to use and require steep learning curves in terms of creating the circuit diagrams and entering mathematical equations. Therefore, there is a need for new educational tools that students can use to learn circuit theory and that provide interactive feedback and assist in learning (as with existing software packages), yet maintains a simple-t-use interface that lets students enter circuit diagrams and mathematics as if they were using pencil and paper.

Moreover, unlike general education classes, common analysis techniques for teaching introductory electrical circuit classes are mostly new, and students are exposed to methods for the first time. This applies to EE and non-EE majors. For EE majors, it is important for every student to be able to grasp important circuit analysis concepts and techniques in order to succeed in the following electrical engineering courses in their program of study. However, most students are not able to understand such introductory courses, not because of a lack of attention, but due to the different learning pace that each student possesses. Therefore, students are not able to build a strong circuit analysis understanding as a foundation for later courses. These introductory courses are generally taught in a large group setting, which reduces the professor's ability to ascertain if the material is understood. Therefore, there is a need for a fully structured methodology to tutor engineering students to formulate effective strategies that helps them learn, retain and apply different concepts of circuit analysis.

The proposed approach is the use of a tool that will allow students to learn circuit analysis methods interactively with a touch of a button!

III. SYSTEM ARCHITECTURE

*e*Tutor is designed to provide personalized feedback that will guide the student through solving difficult problems in basic circuit analysis. This is done by guiding students to solve circuits symbolically and not just numerically. This feature will allow the student to understand better the analysis method being taught with dynamic feedback. Depending on the error being generated, the *e*Tutor will search for the message that best fits the description of the error, using a mechanism that is very similar to a programming language compiler.

In its current version available online,[Haddad, 3] the tool was developed using Java programming language[Sun, 6] and MySQL[MySQL, 4] as a backend to collect data for testing purposes. This database can also be used to collect feedback for instructors. However, this option is not implemented yet in the current version of *e*Tutor.

Besides using MySQL, a Microsoft Excel workbook was used to save a problem's information during students' interactions. The tool encapsulates an Excel file that contains each problem's information. In its core, *e*Tutor consists of the following components:

Graphical User Interface

The *Graphical User Interface* (GUI) contains the collection of screens that serve as a platform for interaction between the student and the *e*Tutor program. Generic GUI components were developed for the *e*Tutor problems that show any selected problem and increase the interaction level between the machine and the user. The tool then takes the user input, passes it to the processing component, receives the results and then displays it to the user. Figure 1 shows the *e*Tutor's main GUI interface screen. The user will be guided through the following steps in order to use the system
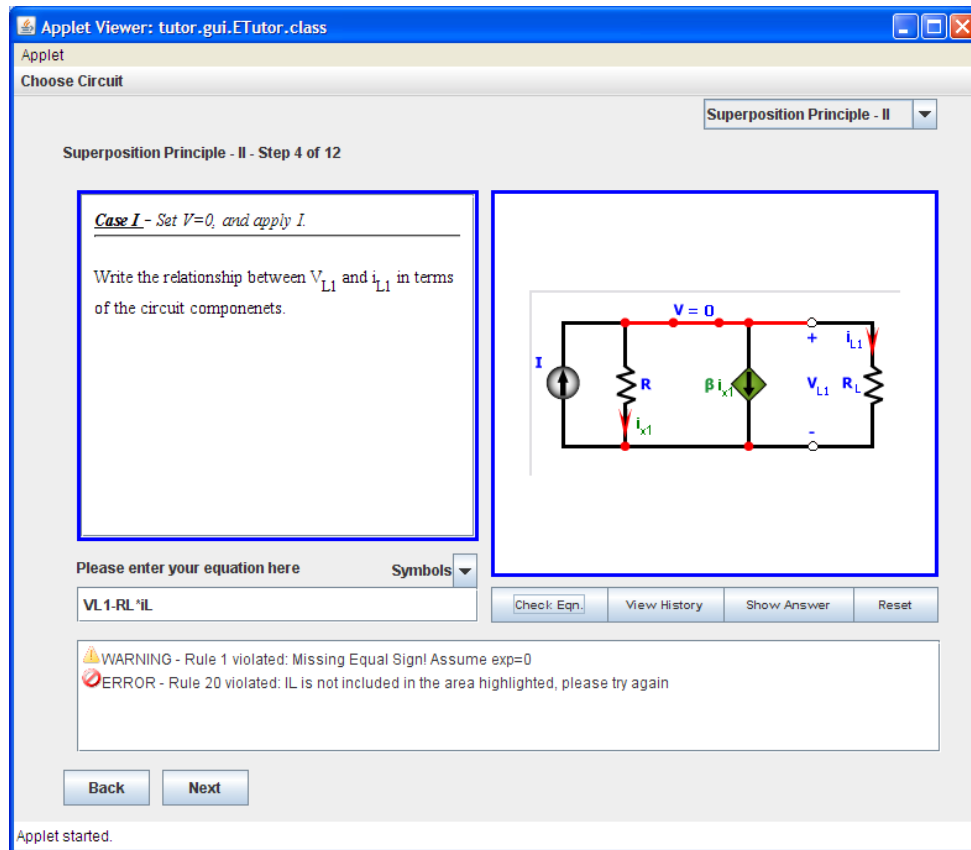

Figure 1: *e*Tutor Main Screen

- The user selects the circuit example of interest from the drop down menu. The Excel file mentioned earlier has several circuits that will appear in this menu. Furthermore, the system is extensible in a way the instructor can add circuits easily.

- The *e*Tutor loads the selected example and shows the first step for the user. The user then can walk through the example step by step using the navigation buttons. Each step provides the needed description and a circuit image associated and, if applicable, an input box for the user equation is displayed.

- The output box at the bottom of the *e*Tutor window shows the results of the parsing and analysis operation. This box mainly displays all errors, warnings and success messages generated during processing (See Figure 2).

- The *e*Tutor provides a way to view the history of answers and error messages for each problem, and allows the user to see the correct answer. There is also a reset button and a drop down menu to insert special symbols like α, β and π that are normally encountered in an introductory circuit course.

- A screen that allows the user to solve the circuit numerically is given as an option for the user after the last step of the problem is passed.

Database Interface

The *Database Interface* is responsible for database interaction. The *e*Tutor can connect to two different databases: a local database that contains the problems and the associated steps, and a remote database to collect users' answers and perform results analysis. Activated by using a certain switch, the tool can perform authentication and actions logging for each user on a remote database. This option allows the authors to collect valuable information on how users react to certain problems and, as a result, fix the presentation of those problems.
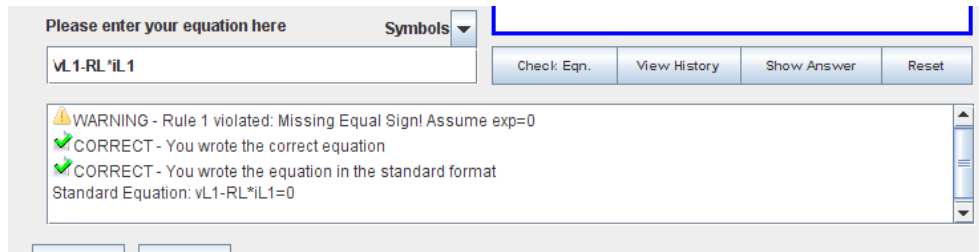

Figure 2: Example of a Correct Answer Report

Processor

The *processor* is the core component in the system. When the user enters the desired equation, the processor is handed the user input, several steps are performed on that equation, and the result is a set of errors and/or warnings that are displayed to the user.

The first step of the input analysis is the preprocessor. Using some information from the problem itself, the preprocessor tries to resolve any missing parts of the equation. Some parts of the equation that are being handled in this phase include the equal sign, the right part of the equation and any missing multiplication signs.

In order to understand the user's input and to produce accurate results, the system is pre-preloaded with a customized parser and syntax analyzer. The output from this stage is a syntax tree that holds the information of the user equation.

The last step in the processor is running the rules checker. This step uses pseudo-runtime defined rules, where the error messages for these rules are dynamically read from the database. However, those rules are built into the system. Performing almost like a compiler, the rules checker checks the syntax tree against the defined rules and compares the user equation with the equivalent correct equation. *e*Tutor then builds the list of errors and/or warnings that will be displayed to the user at the bottom of the window.

Equation Solver

The *equation solver* handles the numerical solution for the circuit. This feature is shown in Figure 3. After the user finishes solving the problem, they will be given a choice of interacting with the circuit by entering their own numerical values. This can be done using the set of input boxes that appear at the left side of the screen, where each box corresponds to an element in the circuit. *e*Tutor will then use the set of equations for that specific circuit to solve the problem numerically. The boxes that appear at the bottom of the screen are used to display the output of solving these equations. Each box corresponds to a calculated value in the circuit. *e*Tutor updates the calculated values promptly when the user changes the value of any element in the circuit.

IV. EXPERIMENT DESIGN

Experiment Objective

A Beta version of the *e*Tutor was tested to measure the students' reaction to the tool, and to prove that students that use the software perform better in class. This study compares the performance of those students that only have lectures and reading materials with students that also use this tutoring tool.

Experiment Approach

One section of the introductory electrical circuit class (EGN 3373) at University of Central Florida was chosen to participate in this study. This class is targeted to incoming engineering freshmen and is typically the student's first course in electrical engineering. In this class, half of the students were selected at random to participate in the study. They were instructed to log on into the *e*Tutor website and go through the methods currently provided (Mesh and Nodal analysis). During a two-week period, the class continued as normal, however, half of these students were given access to access the *e*Tutor at their convenience. No pressure was given to the student to learn the material in a given time. It was clearly explained to students that this was a supplementary tool to help them learn the material at their own pace.
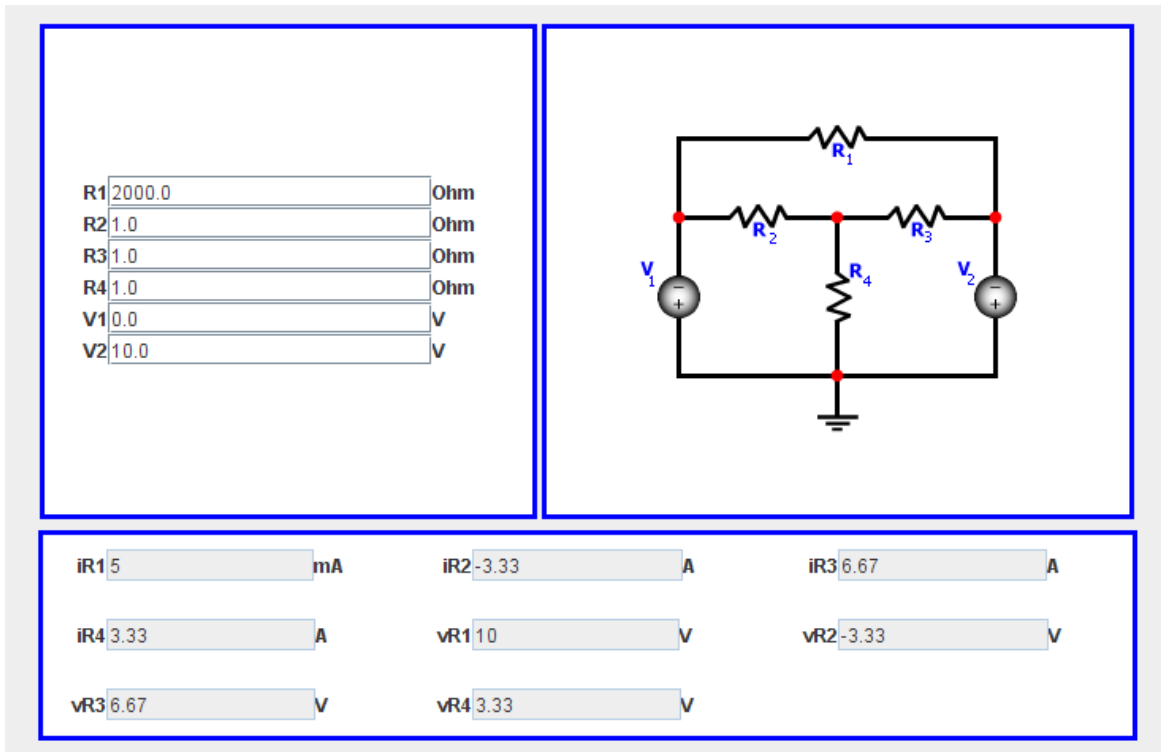

Figure 3: Equation Solver

Survey Overview

After using the Tutor, students were given a survey consisting of nine questions. The nine questions tackled various aspect of the *e*Tutor such as:

- How easy was the *e*Tutor to use?

- Did the illustrations that each step provided help the student better understand the problem?

- Where all the instructions clear and to the point?

- Was the feedback provided on every formula error helpful?

- Did the *e*Tutor help the student better understand the circuit analysis method?

- Did the student feel that it was better to break the problem into steps as the *e*Tutor did?

- Did the student feel more confident on the material now after using the *e*Tutor?

- If more problems were to be provided, would the student use the *e*Tutor?

- Would the student use the *e*Tutor on a daily basis throughout the semester?

The possible responses for this aspect of the *e*Tutor were: Strongly Agree, Agree, Neutral, Somewhat Agree, and Disagree. All the responses were recorded and are shown later in this paper.

V. RESULTS

The survey results from the students at University of Central Florida were recorded and analyzed. Results from this survey are shown in Figure 4, which gives an overview of the student's reaction towards the eTutor. A total of 77.77% of student responses were positive (strongly agree and agree). Only 16.67% of the students surveyed had a neutral response and less than 4% disagree on the effectiveness of the *e*Tutor. However, Figure 4 only shows the overall result of the *e*Tutor.
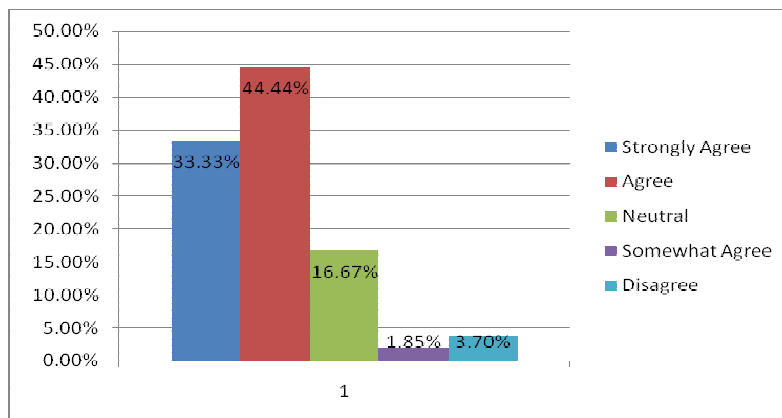

Figure 4: Student Reaction Towards the *e*Tutor

In order to improve the tool, it was necessary to analyze further the negative responses. First, we were able to note which of the questions asked received a negative response (disagree). Only two of the nine questions asked received the negative response. The first question that received negative response stated whether all of the instructions for solving each problem were clear and to the point. Approximately 16.67% of the responses for this question were negative. The second question that received a negative response was regarding the usefulness of the feedback provided by the tool when the student makes a mistake. Likewise, 16.67% of the total responses for this question were negative. Although these two questions only represent 3.7% of the overall responses, it is important to note them and improve the weaknesses of the tool.

Besides the questions, the survey included a comment box. Most of the surveys that included negative responses had comments in them. For example, one student suggested having a better step-by-step explanation if a problem occurs. Because we want to assure that every student understands every single step, this comment alone is under strong consideration. Each step is being reviewed and improved if needed.

In the same manner, textbook publisher John Wiley and Sons Inc. conducted a research study also to note student reactions towards the *e*Tutor. With the publisher's survey, students were able to grade their experience using the *e*Tutor. Results were noted and are shown in Table 1.

Essential	Highly Useful	Somewhat Useful	Not very useful	Useless
13%	48%	35%	4%	0%

Table 1: John Wiley and Sons Results on Student experiences when Using *E*Tutor

The results obtained from John Wiley and Sons are very similar to the results shown in Figure 4. The majority of students found the *e*Tutor to be at least somewhat helpful. Another aspect of the publisher's that was very similar to the study conducted at UCF was that about 4% of the students were not satisfied with the software.

VI. RELATED WORK

Several circuit tutoring software programs have been developed for students. However, none of them appears to be as highly interactive as the *e*Tutor. By not providing proper feedback to allow students to know their current progress, it becomes hard to keep them interested in the material. It is also best for students to know where in the analysis he or she made a mistake, if any. For example, one of the supplementary materials offered by John Wiley & Sons "Introduction to Electric Circuits[Dorf, 2]," lets the student input a numerical answer of the entire circuit analysis. Figure 5 illustrates how other circuit tutoring software attempts to teach students a Mesh analysis method. If the student wrote the wrong answer, then Figure 6 shows how the software reacts to the student's input. The feedback offered only mentions if the answer was correct or wrong.
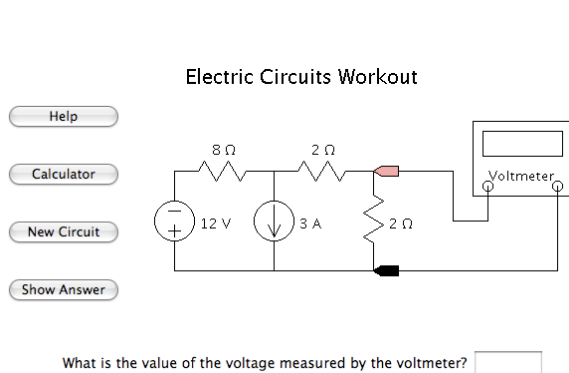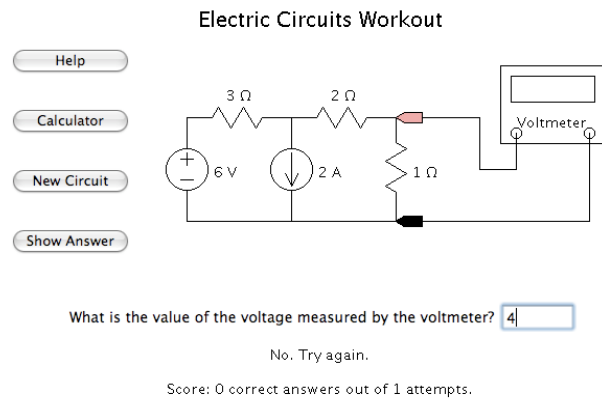
Figure 5: Electric Circuits Workout

Figure 6: Electric Circuits Workout

Similarly, other circuit analysis tools were developed to mimic dynamic feedback for the user. Figure 7 shows a tool offered at the McGraw-Hill Higher Education's website[Website, 8]. As it can be seen in Figure 8, it was noted that the way each problem is set up is to give each problem a few static messages. When the user inputs an error, each error message will appear in the order the author sets it. In other words, no matter what the error is, the software will display the same error order until it runs out of messages. The student will not know exactly what was wrong with the equation if the message does not apply to the error, as the feedback appears to be dynamic when, in reality, it is composed with static messages

Consider the circuit below.
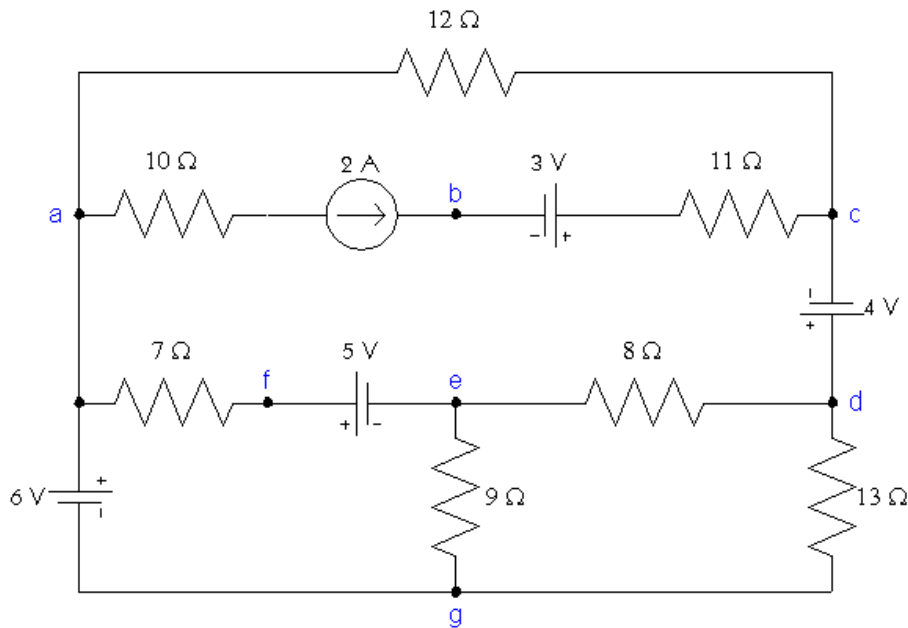
Several points on the circuit are identified by the letters **a** through **g**. Some of these are essential nodes, serve as a reference node, some are more convenient than others. The intelligent engineer will select the to be written.

Which point (**a** through **g**) do you think is the best choice for the reference node?

node [   ]

Figure 7: Tutorial on the Node Voltage Method - Network Analysis Tutorials

There are other electrical circuits tutoring tool that have provided us with great ideas for improving the overall performance of our software. J. R. Pimentel *et. al* [Pimentel, 5]from Kettering University introduces effective ways to illustrate to the student the changes in voltages and current through graphs. The software uses graphical representations and is highly interactive. For example, it uses spread bar graphs to better illustrate the difference when resistor values are changed.

*e*Tutor is not the first symbolic circuit simulator ever developed. However, it is unique when all features combined together are considered. Some circuit tutoring tools such as KIRCHHOFF[Coulon, 1] were developed to handle symbolic analysis. However, dynamic interaction with students in the circuits or methods that are tutored is limited.

VII. CONCLUSION

In this paper, a new interactive tool known as the *e*Tutor, is introduced for the electrical circuits' analysis courses in electrical engineering. Detailed discussion of tool design and operation were given. We presented the results of our study conducted on a class of electrical circuits at University of Central Florida, which verified a significant improvement in course performance as well as positive feedback from students who used the tool. *e*Tutor provides similar feedback to that of an instructor — without the instructor being present with the student. The *e*Tutor code is designed to be an excellent tool that successfully tracks mistakes and provides the user with specific feedback. Many improvements can be added to the tool, these include adding more customized rules, and accordingly, more

significant error messages, to target the finest details in the user's answer. Also, more intelligence needs to be incorporated to allow the tool to anticipate the user's intention and understand the moment he or she entered the answer in the first place.
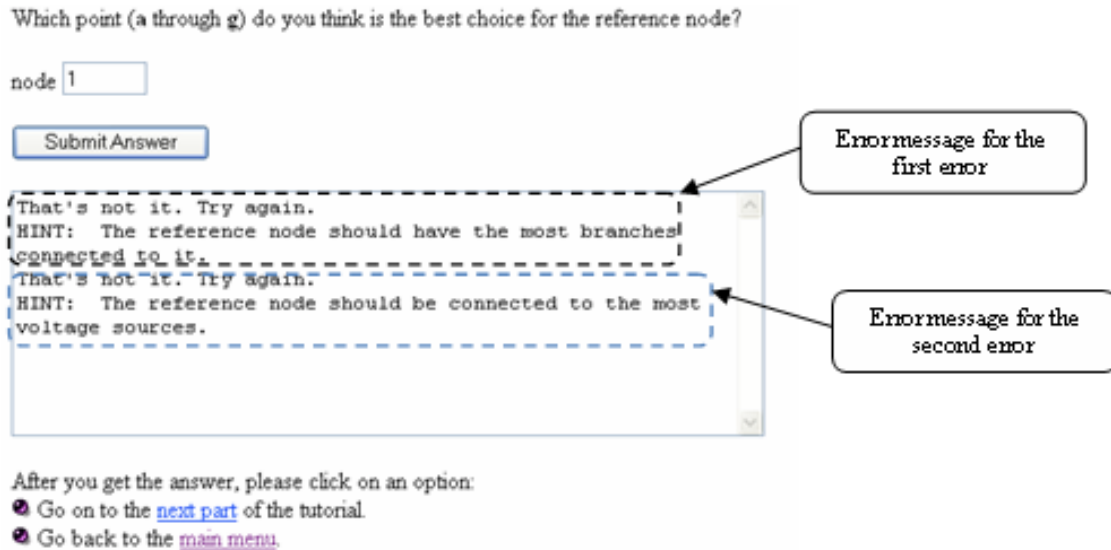

Figure 8: Output from the Node Voltage Method – Network Analysis Tutorials

VIII.   REFERENCES

1.   Coulon, F.d., *KIRCHHOFF: An Educational Software for Learning the Basic Principles and Methodology in Electrical Circuits Modeling.* **IEEE Transactions on Education, 1993. 36(1): p. 4.**
2.   Dorf, R.C., *Introduction to Electric Circuits.* **7 ed. 2006: John Wiley & Sons.**
3.   Haddad, G. *eTutor Homepage.* **2007; http://ecircuits.eecs.ucf.edu/eTutor/eTutor++/eTutor++.htm.**
4.   MySQL. *MySQL Homepage.* **http://www.mysql.com/.**
5.   Pimentel, J.R., *Design of Net-learning Systems Based on Experiential Learning.* **JALN, 1999. 3(2): p. 27.**
6.   Sun Microsystems. *Java Homepage.* **http://java.sun.com/.**
7.   UCF. *UCF Unergraduate Course Catalog.* **2007; http://www.catalog.sdes.ucf.edu/current/.**
8.   Network Analysis Tutorials. *Network Analysis Tutorials.* **2004; http://www.mhhe.com/engcs/electrical/hkd/tutorials/Tut4-1.htm.**

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