The Effect of ElectronixTutor on Undergraduate Students' Acquisition of Conceptual Learning, Problem Solving, and Model Building of Electronic Circuits

Shi Feng
Computer and Information Technology
Purdue University
West Lafayette, U.S.A.
https://orcid.org/0000-0003-0675-6450

Alejandra J. Magana
Computer and Information Technology
Purdue University
West Lafayette, U.S.A.
https://orcid.org/0000-0001-6117-7502

***Abstract*—We investigated whether an intelligent tutoring system, ElectronixTutor, improved students' types of knowledge, including conceptual learning, problem-solving, and model building in the domain of electronic circuits. Specific research questions were (1) Can students improve their deep learning through interacting with ElectronixTutor through conceptual learning, problem-solving, and model building modules? And (2) What are student learning characteristics as they proceed through each model and learning mode? We conducted a recorded interview procedure with 10 participants as they learned with ElectronixTutor, and gave them a pre-, mid-, and posttest in order to assess their overall learning gain as well as learning transfer. We found that, although there were no significant effects due to our small sample size, the results from the means suggest both learning gain and learning transfer. Qualitative analyses were conducted on each of the three different learning modes. Collectively we found that participants were very good at problem-solving using equations and writing formulas but struggled on the application or conceptual questions. Our study suggests that there is a need for building or improving more sophisticated learning or tutoring technologies on STEM domains that focus on the integration of knowledge and skills.**

Keywords*—intelligent tutoring systems, electronic circuits, learning gains

I. INTRODUCTION

There is a critical need in the United States to increase the number of skilled STEM graduates over the next decade [1]. The STEM domains of Physics and Engineering, in particular, are perceived to be inaccessible to learners since they involve learning concepts that are abstract, counterintuitive, and difficult to understand [2, 3]. Fortunately, technological advancements have made it possible for the continuous adoption of online learning environments in higher education [4]. A noted type of online environment is the development of intelligent tutoring systems (ITS), which are artificially simulated learning environments, typically with agents, that seek to mimic classroom or tutoring sessions [5].

Intelligent tutoring systems have had success with increasing deep learning amongst students by implementing a variety of feedback and pedagogical scaffolding steps that are designed to adapt to the individual zone of proximal development [6]. As opposed to shallow knowledge, deep knowledge is the knowledge acquired through learning that analyzes causal mechanisms, formulates logical explanations, creates support for arguments, and resolves conflicts [7]. Deep learning will usually result in learning transfer, which is when a learner is shown to have improvements in learning and retention from one domain or topic to a new topic or domain [8].

The purpose of the current study is to assess learning gains and transfer of learning in the STEM domain of electrical circuits using the ITS ElectronixTutor with college physics and engineering students. We utilized both quantitative and qualitative approaches in order to investigate how students performed during and after interacting with the ITS, as well as the challenges they faced while acquiring the three learning modes: (1) Conceptual learning through conversations, (2) Problem solving through multiple choice, and (3) Model building through Dragoon (with variable and parameter manipulation). The specific research questions are:

- RQ1: Can students improve their deep learning through interacting with ElectronixTutor through conceptual learning, problem-solving, and model building modules?
- RQ2: What are the characteristics of student learning as they proceed through each model and learning mode?

II. BACKGROUND

Intelligent tutoring systems are computerized learning environments that model a student's cognitive, affective state as well as zone of proximal development to provide instruction that is adaptive to these states [9]. Such adaptivity aims to advance the educational agenda and facilitate ease in individualized and personalized learning, especially in the modern information media age [10]. Intelligent tutoring systems are "intelligent" in that they aim to mimic real classroom learning, often coupled with artificial instructor agents or teaching assistants. AutoTutor [11] is an example of an intelligent tutoring system that uses natural language conversations to model students' knowledge and learning on academic domains such as physics, computer literacy, scientific reasoning, and reading comprehension. The structure of the conversation models a typical human tutoring session that follows an expectation and misconception tailoring [12] dialogue, which is the primary pedagogical method of scaffolding good student answers. Other examples of systems with intelligent conversational agents are MetaTutor for learning biology [13], Betty's Brain for learning Algebra [14], Coach Mike for learning science [15], iDRIVE for deep reasoning question generation [16], OPCOMITS for object-oriented programming [17], Virtual PLC for programmable logic controller education [18], and iSTART for reading comprehension [19, 20]. Reviews and meta-analyses have found that intelligent tutoring systems frequently improve learning over classroom teaching, reading texts, and/or other traditional learning methods. The positive effects sizes (Cohen's d) vary from .005 to 1.08, with an average between .42 to .60. This performance is comparable to human tutors with various expertise levels [21].

A. *Electronics Circuits Learning*

Previous research suggests that it is a difficult pedagogical challenge to teach the STEM topic of electronic circuits [e.g., 22]. Central concepts of electronic circuits include voltage, current, and resistance. The abstract, dynamic, and often intangible nature of these concepts make it difficult to relay accurate information to the students in an easily comprehensible manner. It can be problematic for students to develop a solid theoretical understanding of electronic circuits through practical manipulations, especially without readily available assistance to actively correct any misconceptions as students acquire knowledge on the subject. Too often, students are only provided with an algebraic equation without being shown how the quantitative theory is related conceptually to a causal model of what is happening in the circuits. Thus, students are directly or indirectly taught to rely on mathematical equations and left without understanding deep practical knowledge regarding the underlying physical or qualitative mechanisms [e.g., 23].

In order to bring about conceptual change, teachers and instructors need to provide students with accurate information on electronic circuits and actively scaffold students to correct any misconceptions immediately and multiple times as needed. This is because previous research has shown that students' mental models are exceptionally tenacious and resistant to teaching efforts [e.g., 24]. Hence, learning a difficult and abstract topic such as electronic circuits requires tackling multiple modes of learning. Therefore, the National Research Council [25] has emphasized the promotion of discourse mastery in science and engineering courses so that students can acquire critical learning gains such as scientific knowledge, applications of models, and solving practical problems using acquired knowledge and models. The intelligent tutoring system ElectronixTutor [26] was designed and built to facilitate these three learning modes. We hypothesize that students who already took a foundational course on electronics will acquire higher learning gains in their conceptual learning, problem-solving, and model building on the topic of electronic circuits after interacting with ElectronicTutor.

III. ELECTRONIXTUTOR

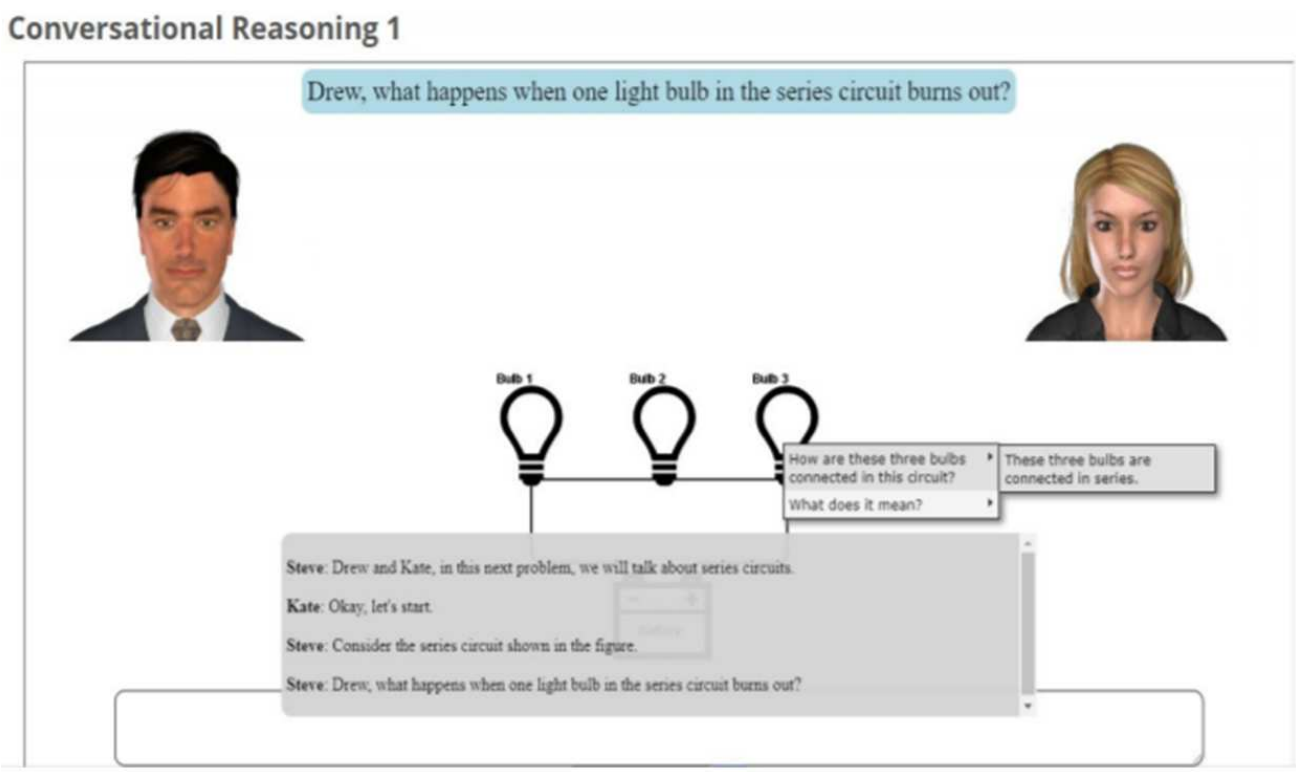

Fig. 1. Screenshot of AutoTutor for promoting conceptual learning.

An intelligent tutoring system for training and learning in the domain of electrical engineering and engineering technology is ElextronixTutor. The US Department of Defense subdivision of the Office of Naval Research (ONR) launched a STEM Challenge Initiative for teams to develop and test an intelligent tutoring system on a STEM topic within only 18 months. The result was a collaboration between the University of Memphis, Arizona State University, BBN/Raytheon, University of Massachusetts, and Worcester Polytechnic Institute to develop an intelligent tutoring system, dubbed ElectronixTutor, the selected topic of electronic circuits. ElectronixTutor was developed as a hybrid ITS to instruct content in electronics and circuits for Navy trainees. It is the most up-to-date development in the online intelligent tutoring environment. It integrates many different ITS and conventional learning resources into a single system [27]. ElectronixTutor consists of three main parts: (1) AutoTutor, which uses conversational agents to promote conceptual understanding (2) ASSISTments, which is a platform for problem-solving using mathematical skills; and (3) Dragoon, which uses simulation for constructing model-based reasoning skills. The following sections will present each component in detail.

A. Conceptual Learning via AutoTutor

The AutoTutor [28] component promotes a conversational exchange while presenting conceptual questions on electronic circuits. Students are engaged with a tutor agent and a peer agent in a natural language, "trialogues" [29], on a designated topic. The agents in the trialogues directly address the student by his/her name when asking the main question and serve functions such as orienting the student to the appropriate graphical representation. This allows the students to contextualize from the concrete image to the deeper concept. A screenshot of AutoTutor is presented in Figure 1.

The AutoTutor Conversational Engine is able to extract partial correct and incorrect responses from natural language input. To do this, each main question has been divided into separate components of a fully correct answer. When a student hits at least one of these components but not all, the agents will follow up with hints, prompts, or pumps in order to guide the learner to eventually elicit the complete, correct answer. AutoTutor's capability to analyze students' knowledge breadth makes it an excellent diagnostic tool to identify the next appropriate problem adapted to the individual learner. This approach has shown to be successful across numerous domains, including STEM topics such as computer literacy, physics, biology, and scientific reasoning.

B. Problem Solving via ASSISTments

ASSISTments [30] are built into ElectronixTutor in order to provide the students with drill and practice problems on the mathematics of basic electronics laws. They are in the most simple format in the system, consist of several multiple-choice questions. The students are presented with multiple-choice questions on circuit basics. The questions typically involve imagery of circuitry, and the students are first asked to calculate current or voltage, then asked to give an explanation for their previous answer by choosing from one of the four explanations. This portion of ElectronixTutor provides a quick and easy assessment for students' mathematical problem-solving skills using algebraic equations. A screenshot of ASSISTments is presented in Figure 2.

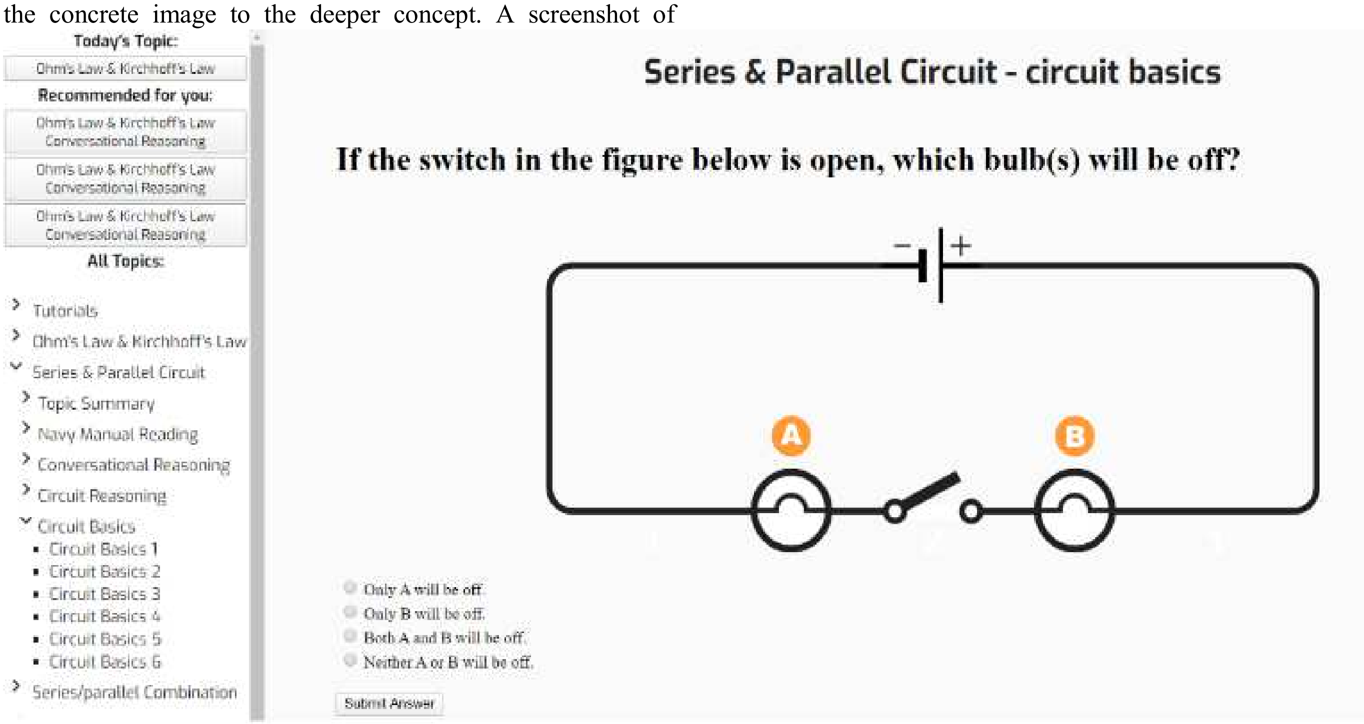

Fig. 2. Screenshot of ASSISTments for promoting problem-solving.

C. Model-based Reasoning via Dragoon

Dragoon [31] promotes students' model-building skills by constructing and manipulating dynamic models of circuits. Learners must manipulate aspects of a complex circuit diagram and demonstrate that variations in one parameter will change the behavior of the circuit as a whole. As a result, Dragoon is there to ensure functional understanding of interacting parts by fostering the development of appropriate mental models. These questions represent the most difficult problems in STEM academia because it incorporates conceptual relationships and mathematical reasoning in a model of complex circuits. The holistic perspective on structures, parameters, and relationships among them requires a comprehensive understanding and deep practical knowledge of electronic circuits. This adds substantial value, ensuring mastery with a high degree of confidence and providing challenges to the most advanced, diligent learners. A screenshot of Dragoon is presented in Figure 3.

Circuits, from the 15 topics in ElectronixTutor for our experiment. These two topics were chosen to correspond with the basic curriculum of physics and engineering education courses at the college level. Within the common university curriculum, these two topics are also typically taught in sequences, with Ohms Law & Kirchhoff's Law taught before Serial and Parallel Circuits. Therefore, we investigated learning transfer by having students first go through the former topic and investigate whether learning that topic resulted in knowledge transfer for the latter.

Pre-, mid-and posttests were used to investigate prior knowledge, learning transfer, and learning gain for the two topics. For the topic of Ohm's Law and Kirchhoff's Law, all three

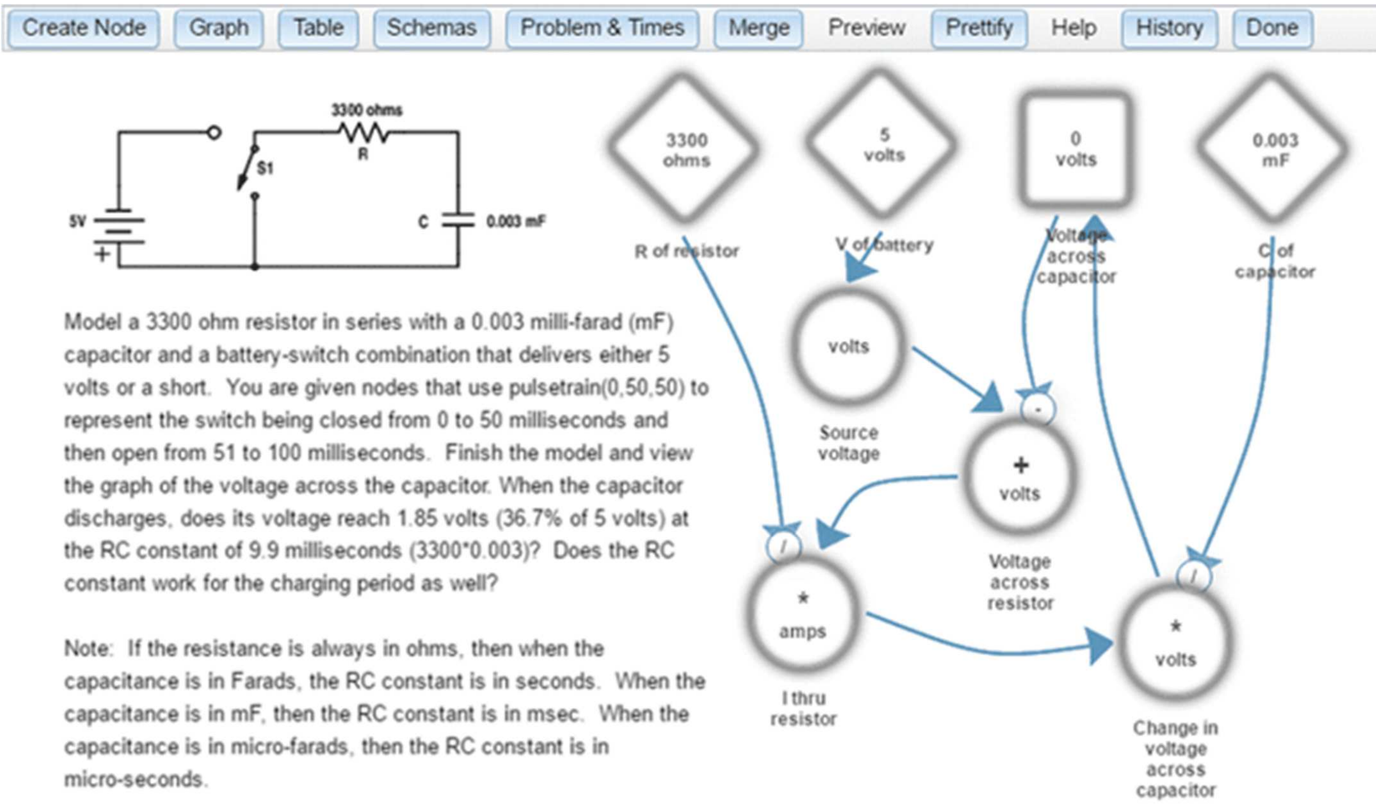

Fig. 3. Screenshot of Dragoon form promoting model-based reasoning.

We are participating in the ongoing empirical testing of ElectronixTutor to validate learning results for the current study. The three particular learning modes that are embedded in the tutoring system: conceptual learning, problem-solving, and model-based reasoning--are in line with prominent national science associations as critical learning achievements for STEM education [25]. The system consists of 15 topics and hundreds of knowledge components that are in line and can be used as curriculum assessments of learners' mastery of electrical circuits. Therefore, we determined ElectronixTutor as a proper learning tool for aiding our college physics and engineering students in learning this particular foundational STEM subject.

IV. Methods

In the current study, we chose two topics in electrical circuits, Ohm's Law & Kirchhoff's Law and Serial & Parallel

learning modes—conceptual learning, problem-solving, and model building—were available; therefore, we had the students go through all three parts. For the topic of Serial and Parallel circuits, only conceptual learning and problem solving were available. This is both due to the nature of the topic and the designated curriculum determined by the experts within ElectronixTutor. All student participants completed both topics and all five parts of ElectronixTutor and all three test assessments.

We hypothesized that: (1) students would show improvements on learning on each of the topics after interacting with ElectronixTutor, as assessed by pre-, mid-, and posttest; (2) Students will show learning transfer between learning the topic of Ohm's Law and Kirchhoff's Law to learning the topic of Serial and Parallel circuits after interacting with ElectronixTutor, as assessed from pretest to mid-test; and (3) Students who displayed struggling but persisted in figuring out solutions will have higher learning gains and learning transfer than students who did not struggle or prone to giving up.

A. Participants and Procedures

This interview study was performed with a population of ten first-year engineering technology students. We performed a recorded interview procedure in order to identify how students interacted with the intelligent tutoring system. In addition, we supplemented our measures with quantitative approaches in the form of a pretest, midtest, and posttest. Before conducting this investigation, we received approval from the Institutional Review Board. Our participants were ten first-year college physics and engineering students (seven male and three female) who volunteered to participate in the experiment for a paid compensation. Before participating in the study, all students had taken a basic circuits course in the past. Seven participants were Caucasians, two were Indian, one was Middle Eastern, and one was East Asian (Chinese). Their ages ranged from 19 to 23 years old. All 10 participants were able to complete the pretest, midtest, and posttest; however, only eight participants' data on the ElectronixTutor portion were able to be used due to two participants' video recording software having issues. So only eight participants' data were analyzed for the ElectronixTutor conversational reasoning portion. Data from the ten participants were included in the problem-solving and model-building portions.

The participants were asked to come in for one full three-hour session, where they first completed the consent form before the start of the experiment. In the experiment, they all completed the following tasks in the described sequence: (1) a pretest for the first topic of Ohm's Law and Kirchhoff's Law. (2) The first interaction with the intelligent tutoring system ElectronixTutor for the first topic of Ohm's Law and Kirchhoff's Law and its three parts consisted of Conversational Reasoning, Circuit Basis, and Model Building. (3) A mid-test for both the first topic of Ohm's Law and Kirchhoff's Law and the second topic of Serial and Parallel Circuits. (4) The second interaction with ElectronixTutor for the second topic of Serial and Parallel Circuits and its two parts consisted of Conversational Reasoning and Circuit Basis (no model building module available for this topic). (5) The posttest for the second topic of Serial and Parallel Circuits. All portions of the experiment were performed on a computer screen. The participants completed the same pre-, mid-, and posttests using the online survey service Qualtrics. The presentation of the experiment was all done in the same order for examining their learning transfer. Data Collection and Data Analysis Methods

The procedure for the qualitative data analysis was conducted in the following fashion: an expert student grader and an engineering professional graded nine participants (one data was irretrievable from the error due to incorrect configuration of the system). The student expert was for the AutoTutor portion of Conversational Reasoning and the Dragoon portion of model building. The Conversational Reasoning was graded on the students' open-ended input response for the questions asked by the agents. The input answers were graded using five categories: (1) Completely correct—the student's input was complete and correct in all parts of his/her answer. (2) Partially correct—the student's input was correct; however, incomplete. (3) Incorrect—the student's input had any incorrect part to the question that was asked. (4) Irrelevant— the student's input was not directly relevant to the question that was asked. And (5) Off-Domain—the student's input was not answering a question that was within the domain of the subject matter being asked.

The model building of the first topic was graded following a thematic analysis approach: as the student proceeded to solve the problem via model building, we looked for: (1) Did the student understand the task set before him/her? (2) Was the student struggling to understand instructions or solving the problem? If so, how were they struggling? (3) At what point did the student figure out how to proceed with the problem? What tools did they use from the module for figuring out the solution? (4) was the student correct in their solutions? If not, what was the misconception they had when they solved the problems? And finally, (5) was the student able to complete the task all the way? The Circuit Basis module was automatically graded from the system's storage of correct multiple-choice responses. Finally, learning gains and learning transfer were calculated from the difference scores between the pre-, mid-, and posttests. Due to the small sample size, only basic statistics and qualitative analyses were used for the current paper.

V. RESULTS

The results are presented in three main sections, each addressing the hypotheses tested through this study. First, we tested for specific learning gains from pretest to posttest. Second, we evaluated students' conceptual learning based on their responses to conversational reasoning, problem-solving based on their multiple-choice responses to the circuit basis problems, and finally, their model building based on their selection and construction of models in the dragoon portion within the interaction with ElectronixTutor.

A. Learning Gains

A paired *t*-test was conducted to compare the proportion of correct responses from pretest to posttest. There was a non-significant difference with respect to an alpha of .05 for proportion of correct responses for pre-test ($M = .57$, $SD = .21$) and post-test (($M = .72$, $SD = .16$), $t(9) = 2.26$, $p = .07$). However, the non-significant result is likely due to the small sample size. The means of the scores from pretest to posttest seem promising. There seems to be, on average, a 15% learning gain from pretest to posttest after interacting with ElectronixTutor.

In addition, we tested the participants' knowledge transfer of Serial and Parallel Circuits in the mid-test before engaging with ElectronixTutor. A paired *t*-test was conducted to compare the proportion of correct responses from pretest to mid-test. There was a close to significant difference with respect to an alpha of .05 for proportion of correct responses for pre-test ($M = .57$, $SD = .21$) and post-test ($M = .64$, $SD = .16$), $t(9) = 2.26$, $p = .07$). We then separated the question items for the two topics and conducted paired t-test for each. We found that, although as predicted there was a non-significant difference, on average our students had an approximately 3-9% learning gains for both relative to the pretest (Ohm's Law: $M = .60$, $SD = .14$, $t(9) = 2.26$, $p = .60$; Serial Parallel Circuits: $M = .66$, $SD = .30$, $t(9) = 2.26$, p

= .16). In fact, the average performance on the Serial and Parallel Circuits seemed to be higher than Ohm's Law and Kirchoff's Law, even before the students interacted with ElectronixTutor on the topic. However, the average performance between the mid-test portion of Serial and Parallel Circuits and the posttest on just the topic of Serial and Parallel Circuits was not so different, even slightly worse performance, $t(9) = 1.83$, $p = .80$.

B. Conversational Reasoning

A Cohen's Kappa was conducted to assess the interrater reliability between the grading of the student expert and the expert engineer. There was a Kappa agreement of .69. The vast majority (80%) of disagreement occurred on the interpretation between "partially correct" and "incorrect," which both graders found it difficult to match perfectly with the students' responses which tended to be brief and short. After resolving this discrepancy in understanding the two grading category concepts, there was an agreement of .85.

Averaging the scoring from the two graders, the results show that participants were completely correct 55% of the time on the topic of Ohm's Law and Kirchoff's Law, and 47% of the time on the topic of Serial and Parallel Circuits. In addition, participants were partially correct 11% of the time on the topic of Ohm's Law and Kirchoff's Law, and 17% on the topic of Serial and Parallel Circuits. Overall, participants had a 43% passing rate for getting the full and completed answer on the first pass without hints, a 30% additional passing rate for the second pass after the first hint was given, and a 27% additional passing rate after the second and last hint was given.

Dividing the topics, participants had a 46% passing rate on the first pass without hints on Ohm's Law, 25% additional passing rate on the second pass after the first hint was given, and 29% additional passing rate after the second and final hint was given. Participants had a 34% passing rate on the first pass for Serial and Parallel Circuits, 26% additional passing rate for the second pass after the first hint was given, and 41% additional passing rate for the third pass. It is interesting that our participants performed much worse on Serial and Parallel circuits in the conversational reasoning section relative to their multiple-choice mid-test portion of the topic. Table 1-2 shows all the passing rates of the 8 participants for both topics.

TABLE I. OHM'S LAW PASSING RATE

Participant	First Pass Correct	Second Pass Correct	Third Pass
1	0.42	0.17	0.41
2	0.42	0.50	0.08
3	0.17	0.08	0.75
4	0.42	0.25	0.33
5	0.42	0.08	0.50
6	0.33	0.58	0.09
7	0.92	0.08	0.00
8	0.58	0.25	0.17

TABLE II. SERIAL AND PARALLEL CIRCUITS PASSING RATE

Participant	First Pass Correct	Second Pass Correct	Third Pass
1	0.00	0.25	0.75
2	0.50	0.50	0.00
3	0.50	0.00	0.50
4	0.00	0.20	0.80
5	0.20	0.60	0.20
6	0.33	0.17	0.50
7	0.83	0.17	0.00
8	0.33	0.17	0.50

The results of the grading showed that students performed the worst on question items that presented a drawing of a circuit and asked the student to interpret a voltmeter or rheostat outcome (e.g., "If we increase the rheostat resistance, what would happen to the reading of the voltmeter?"). On the other hand, the students performed the best on question items that simply asked the student the mathematical formula of calculating current or voltage (e.g., "How is the total voltage of a series circuit calculated?"). Collectively, the results suggest that the students mostly possessed route memorization or shallow knowledge of the topics but struggled with the application or deep knowledge of the concepts.

C. Circuit Basis

On average, participants performed at a higher level on this portion of ElectronixTutor with an average score of .84, with a score of .93 on the topic of Ohm's Law, and a score of .81 on the topic of Serial and Parallel Circuits. The problems they tended to struggle with were problems that required the participants to be more meticulous, such as "how many closed paths can you find in the circuit drawing below?" It is reasonable to assume that one of the main reasons for the high performance was due to the nature of the testing format, which consisted of multiple choice. This would understandably lessen participants' cognitive load and tackle more test-taking skills that the students were more familiar with.

D. Model Building

The model building involved asking each student to write out equations and formulas based on a presented circuitry drawing using the specific expressions in the system. Each model building module was set up as a series of individual equations and expressions that will link to each other as a full model. Participants were asked to go through each individual equation represented by a blue triangle problem. The module allows for multiple tries. Grading was done entirely by viewing their video interactions, which means only six participants' responses were recorded. On average, participants had four tries before solving the problem and moving on to the next triangle. On average, participants had a 53% failure rate (i.e., never came up with the correct equation, but the system allowed them to move on). In general, most student participants demonstrated understanding of Ohm's Law and Kirchoff's Law via model building; however, the struggle students experienced the most was determining what the Dragoon program was asking for in terms of the syntax. Among the approximately half of the participants who were able to figure out the format and the syntax of the model simulation, most were successful in building their models based on the problem given. This is consistent with the previous findings that the participants seemed to excel the most on problems involving writing equations and using formulas. See Table 3 for a complete assessment of each of the six participants.

TABLE III. MODEL-BUILDING ASSESSMENT RESULTS

Part.	Model	Summary
1	1	Participant completed the first module but then moved on to the second question.
	2	Participant completed the first module but then moved on to the third question.
	3	Participant struggled heavily on the first module and then left the model.
2	1	Participant got stuck in the first module and when trying to determine the value of the current through resistor R1. Otherwise, the participant did not struggle with the modules.
	2	Participant had no issues with this model other than determining the function type. Subject demonstrated knowledge of Ohm's law.
	3	Participant occasionally got tripped up on negative vs. positive current flow but mostly demonstrated knowledge of basic KVL.
3	1	Participant struggled in the first submission to figure out what the program is asking for, but in the following tasks, they were able to complete the tasks relatively quickly. Participant successfully applied knowledge of Ohm's law to the model building. In one instance, the participant entered an answer that was correct but not what the program was looking for.
	2	Participant quickly finished the module without any issues and demonstrated a strong knowledge of Ohm's law
	3	Participant struggled with KVL in the first module but quickly picks it up and applies it to the following modules.
4	1	Participant completed the model with relative ease, only struggling on the math portion of the resistance of R2, seemingly due to decimal places. Subject demonstrated knowledge of Ohm's law.
	2	Participant completed every question on the first try other than the type for I through R. Subject demonstrated knowledge of Ohm's law.
	3	Participant easily completed the module and demonstrated their knowledge of KVL.
5	1	Participant heavily struggled and failed to model on the first module. They attempted to fill the expression section with numerical answers.
	2	Participant learned after the first module to fill in the expression box with conceptual expressions rather than numerical answers. Participant struggled with determining the type but demonstrated knowledge of Ohm's law.
	3	Participant stumbled on the value of current for I3 but had no issues with the other modules. Subject demonstrated knowledge of KVL.
6	1	Participant stumbled a few times determining the type and what the question was asking for but otherwise was able to answer the questions correctly. Subject demonstrated knowledge of Ohm's law.
	2	Participant correctly answered every question on the first try. Subject demonstrated knowledge of Ohm's law.
	3	Participant incorrectly answered the type for I2 but was correct on the first try for everything else. Subject demonstrated knowledge of KVL.

VI. DISCUSSION AND IMPLICATIONS

We set out to investigate whether the recently developed intelligent tutoring system for electronic circuits, ElectronixTutor, would assist students in learning various subjects in the topic of electronic circuits. We used both quantitative and qualitative methodology to assess the students' learning gains, learning transfer, and learning process while interacting with the system. Overall, we found clear indications of learning gains evaluated from our pretest to posttest. The current results are consistent with the previous findings that students tend to struggle with a deep understanding of concepts such as application-related problems and rely more on shallow knowledge such as writing formulas and solving problems using memorized equations [e.g., 32]. Findings from this study are also consistent with the literature on the effectiveness of intelligent tutoring systems for improving student learning [6, 33, 34].

The implications for teaching and learning from this study relate to the need for learning opportunities that can guide students to make connections between different types of knowledge in the same domain (i.e., declarative, procedural, schematic, strategic). Specifically, in this study, ElectronixTutor allowed students to connect conceptual knowledge with mathematical knowledge, with model-building knowledge, all on the same topic. It is also important to point out that all students who participated in this study had already taken an introductory physics course at the college level where they learned about the concepts. As indicated in previous literature on conceptual change [2], some concepts in STEM are difficult to learn, challenging, and counterintuitive. When taught via formal instruction, electric circuits are one of such concepts that often result in students' misconceptions [35]. One important aspect of learning with intelligent tutoring systems (or learning with actual tutors) is that those can scaffold the learning process allowing learners to demonstrate their knowledge, and if incorrect or incomplete, give immediate feedback and correction as students learn. Thus, allowing for individual learning [36].

An implication of this work relates to the need for further qualitative research to investigate nuanced misconceptions students may still hold and how the tutor addresses those misconceptions. This could be done by asking students to think and talk aloud as they work with the system to explain their reasoning. Student feedback on using ElectronixTutor can be collected at this time.

Regarding implications for the design of intelligent tutoring systems, our experience in conducting this study following a recorded interview procedure made us realize that there is also a need for improving interactions with the system. For instance, the animated characters in AutoTutor were uncanny. Similarly, we noticed that there was a learning curve for interacting with Dragoon, as the logic for building the models was not intuitive. Furthermore, advances in artificial intelligence can be incorporated into the system to improve feedback mechanisms [37].

VII. Conclusion, Limitations, and Future Work

The goal of the current study was to investigate student learning of the STEM subject of electronics using the intelligent tutoring system ElectronixTutor. Although our current sample size is small, which would inevitably result in non-significant effects, and the intervention could have taken longer than three hours, our results are promising in showing that ElectronixTutor seemed to help with learning. Our future direction aims to develop better instruments of assessment to see how we can improve students' deeper conceptual understanding of applied concepts. We also suggest a need to build or improve more sophisticated learning or tutoring technologies in STEM domains that focus on these skills. Although there are some challenges ahead to make intelligent tutoring systems more intuitive and widely available, like ElextronixTutor, we believe that intelligent tutoring systems have a strong promise for being an appropriate mechanism to repair fragmented ideas and consolidate knowledge on a given topic. Thus, research in this area, particularly in STEM domains, is much needed.

References

[1] S. Olson, and D. G. Riordan, "Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President," Executive Office of the President, 2012.

[2] M. T. Chi, and R. D. Roscoe, "The processes and challenges of conceptual change," Reconsidering conceptual change: Issues in theory and practice, pp. 3-27: Springer, 2002.

[3] R. Land, J. H. Meyer, and M. T. Flanagan, Threshold concepts in practice, Rotterdam, Netherlands: Sense Publisher, 2016.

[4] D. R. Garrison, and H. Kanuka, "Blended learning: Uncovering its transformative potential in higher education," The internet and higher education, vol. 7, no. 2, pp. 95-105, 2004.

[5] R. A. Sottilare, R. S. Baker, A. C. Graesser, and J. C. Lester, "Special Issue on the Generalized Intelligent Framework for Tutoring (GIFT): Creating a stable and flexible platform for Innovations in AIED research," International Journal of Artificial Intelligence in Education, vol. 28, no. 2, pp. 139-151, 2018.

[6] W. Ma, O. O. Adesope, J. C. Nesbit, and Q. Liu, "Intelligent tutoring systems and learning outcomes: A meta-analysis," Journal of educational psychology, vol. 106, no. 4, pp. 901, 2014.

[7] A. C. Graesser, "Deeper learning with advances in discourse science and technology," Policy Insights from the Behavioral and Brain Sciences, vol. 2, no. 1, pp. 42-50, 2015.

[8] K. Weiss, T. M. Khoshgoftaar, and D. A. Wang, "Survey of transfer learning," Journal of Big Data, vol. 3, no. 9, 2016.

[9] H. L. Fwa, "An architectural design and evaluation of an affective tutoring system for novice programmers," International Journal of Educational Technology in Higher Education, vol. 15, no. 1, pp. 38, 2018.

[10] A. C. Graesser, C. M. Forsyth, and B. A. Lehman, "Two Heads May Be Better than One: Learning from Computer Agents in Conversational Trialogues," Grantee Submission, vol. 119, pp. 1-20, 2017.

[11] A. C. Graesser, H. Li, and C. Forsyth, "Learning by communicating in natural language with conversational agents," Current Directions in Psychological Science, vol. 23, no. 5, pp. 374-380, 2014.

[12] A. C. Graesser, X. Hu, B. Nye, and R. Sottilare, "Intelligent tutoring systems, serious games, and the Generalized Intelligent Framework for Tutoring (GIFT)," Using games and simulation for teaching and assessment, pp. 58-79, 2016.

[13] M. Lintean, V. Rus, Z. Cai, A. Witherspoon-Johnson, A. C. Graesser, and R. Azevedo, "Computational aspects of the intelligent tutoring system MetaTutor," Applied natural language processing: Identification, investigation and resolution, pp. 247-260: IGI Global, 2012.

[14] G. Biswas, H. Jeong, J. S. Kinnebrew, B. Sulcer, and R. Roscoe, "Measuring self-regulated learning skills through social interactions in a teachable agent environment," Research and Practice in Technology Enhanced Learning, vol. 5, no. 02, pp. 123-152, 2010.

[15] H. C. Lane, D. Noren, D. Auerbach, M. Birch, and W. Swartout, "Intelligent tutoring goes to the museum in the big city: A pedagogical agent for informal science education." pp. 155-162.

[16] S. D. Craig, B. Gholson, J. K. Brittingham, J. L. Williams, and K. T. Shubeck, "Promoting vicarious learning of physics using deep questions with explanations," Computers & Education, vol. 58, no. 4, pp. 1042-1048, 2012.

[17] B. Dogan, and E. Dikbıyık, "OPCOMITS: Developing an adaptive and intelligent web based educational system based on concept map model," Computer Applications in Engineering Education, vol. 24, no. 5, pp. 676-691, 2016.

[18] S. J. Hsieh, and P. Y. Hsieh, "Web - based modules for programmable logic controller education," Computer Applications in Engineering Education, vol. 13, no. 4, pp. 266-279, 2005.

[19] G. T. Jackson, and D. S. McNamara, "Motivation and performance in a game-based intelligent tutoring system," Journal of Educational Psychology, vol. 105, no. 4, pp. 1036, 2013.

[20] D. S. McNamara, T. P. O'Reilly, R. M. Best, and Y. Ozuru, "Improving adolescent students' reading comprehension with iSTART," Journal of Educational Computing Research, vol. 34, no. 2, pp. 147-171, 2006.

[21] K. VanLehn, "The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems," Educational Psychologist, vol. 46, no. 4, pp. 197-221, 2011.

[22] C. Hart, "Models in physics, models for physics learning, and why the distinction may matter in the case of electric circuits," Research in Science Education, vol. 38, no. 5, pp. 529-544, 2008.

[23] J. R. Frederiksen, B. Y. White, and J. Gutwill, "Dynamic mental models in learning science: The importance of constructing derivational linkages among models," Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, vol. 36, no. 7, pp. 806-836, 1999.

[24] M. H. Chiu, and J. W. Lin, "Promoting fourth graders' conceptual change of their understanding of electric current via multiple analogies," Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, vol. 42, no. 4, pp. 429-464, 2005.

[25] C. D. Wilson, J. A. Taylor, S. M. Kowalski, and J. Carlson, "The relative effects and equity of inquiry - based and commonplace science teaching on students' knowledge, reasoning, and argumentation," Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, vol. 47, no. 3, pp. 276-301, 2010.

[26] A. C. Graesser, X. Hu, B. D. Nye, K. VanLehn, R. Kumar, C. Heffernan, N. Heffernan, B. Woolf, A. M. Olney, and V. Rus, "ElectronixTutor: an intelligent tutoring system with multiple learning resources for electronics," International journal of STEM education, vol. 5, no. 1, pp. 15, 2018.

[27] A. C. Graesser, N. Dowell, A. J. Hampton, A. M. Lippert, H. Li, and D. W. Shaffer, "Building intelligent conversational tutors and mentors for team collaborative problem solving: Guidance from the 2015 Program for International Student Assessment," Building Intelligent Tutoring Systems for Teams: Emerald Publishing Limited, 2018.

[28] A. C. Graesser, "Conversations with AutoTutor help students learn," International Journal of Artificial Intelligence in Education, vol. 26, no. 1, pp. 124-132, 2016.

[29] Z. Cai, S. Feng, W. Baer, and A. Graesser, "Instructional Strategies in Trialogue-based Intelligent Tutoring Systems," Design recommendations for intelligent tutoring systems, vol. 2, pp. 225-235, 2014.

[30] N. T. Heffernan, and C. L. Heffernan, "The ASSISTments ecosystem: Building a platform that brings scientists and teachers together for minimally invasive research on human learning and teaching," International Journal of Artificial Intelligence in Education, vol. 24, no. 4, pp. 470-497, 2014.

[31] K. VanLehn, G. Chung, S. Grover, A. Madni, and J. Wetzel, "Learning science by constructing models: can dragoon increase learning without increasing the time required?," International Journal of Artificial Intelligence in Education, vol. 26, no. 4, pp. 1033-1068, 2016.

[32] C. Forsyth, A. Graesser, P. I. Pavlik Jr, K. Millis, and B. Samei, "Discovering theoretically grounded predictors of shallow vs. deep-level learning."

[33] P. Dodds, and J. Fletcher, "Opportunities for new "smart" learning environments enabled by next-generation web capabilities," Journal of Educational Multimedia and Hypermedia, vol. 13, no. 4, pp. 391-404, 2004.

[34] J. A. Kulik, and J. Fletcher, "Effectiveness of intelligent tutoring systems: a meta-analytic review," Review of Educational Research, vol. 86, no. 1, pp. 42-78, 2016.

[35] S. Sencar, and A. Eryilmaz, "Factors mediating the effect of gender on ninth - grade Turkish students' misconceptions concerning electric circuits," Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, vol. 41, no. 6, pp. 603-616, 2004.

[36] M. Bulut Özek, Z. H. Akpolat, and A. Orhan, "A web - based intelligent tutoring system for a basic control course," Computer Applications in Engineering Education, vol. 21, no. 3, pp. 561-571, 2013.

[37] T. Bates, C. Cobo, O. Mariño, and S. Wheeler, "Can artificial intelligence transform higher education?," SpringerOpen, 2020.