Step-Based Tutoring Software for Complex Procedures in Circuit Analysis

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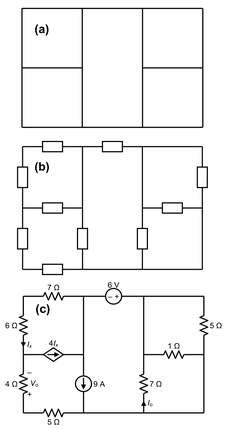
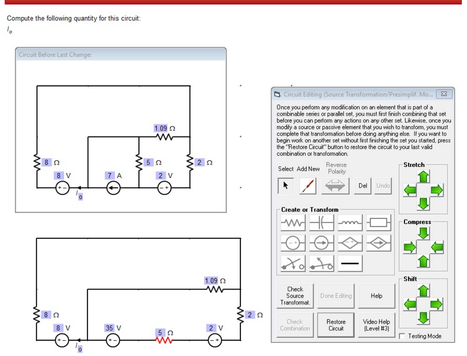
Introduction

- Step-based tutoring, where each step of a student's work is evaluated, is well known to be superior to more traditional answer-based systems (like most commercial publisher-based homework systems), yielding learning gains of 0.76 σ compared to 0.79 σ for expert human tutors and 0.34 σ for answer-based tutors.[1]
- Such systems however require more complex user interfaces to accept various forms of input, which impose learning curves on the student. This is particularly true in subjects like linear circuit analysis, where students must interactively re-draw circuits and write equations in order to carry out complex, multi-step solution procedures such as superposition, source transformations, Thevenin/Norton equivalent circuits, and transient analyses using differential equations.
- Our first research question is therefore, "Can a step-based approach be used effectively when procedures such as interactive circuit editing are required in cognitively complex problem-solving tasks?"
- Our second question is "How will student perceptions and learning outcomes compare between a step-based system and a traditional, answer-based commercial system when performing this type of task?"
- The importance of these questions is related to the foundational nature of topics such as linear circuit analysis for electrical engineering students and their importance to non-electrical engineers as well. Increasing success in courses on this topic is therefore important to improving graduation and retention rates, and it is important to know if step-based tutoring can be effective for that purpose.

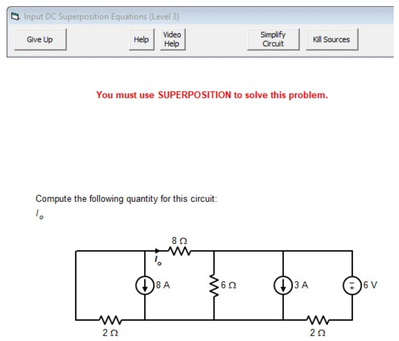
Three-step Process for Circuit Generation



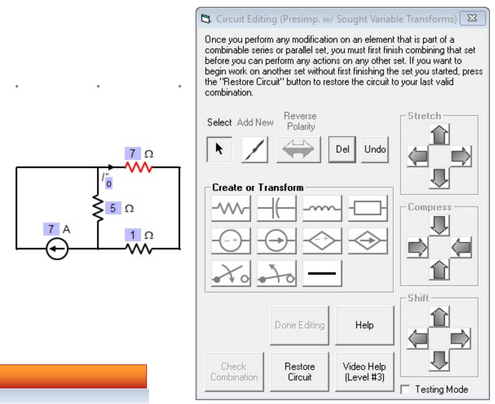
Example of Source Transformation Interface



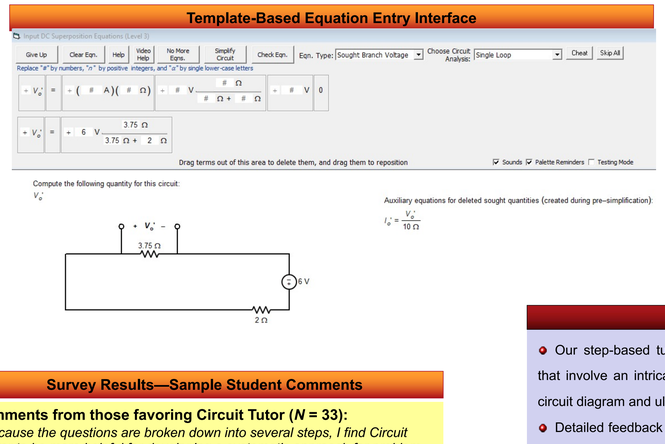
Randomly Generated Superposition Problem



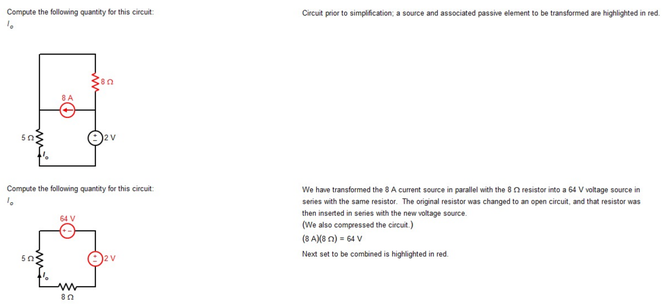
Example of Editing During Superposition Exercise



Template-Based Equation Entry Interface



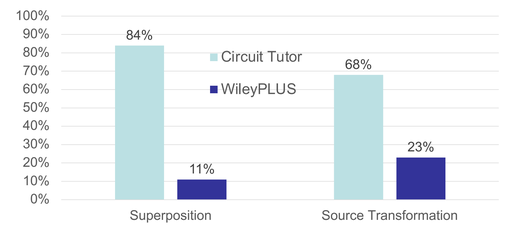
Portion of Example Solution—Source Transformation Problem



Experimental Approach & Qualitative Data Summary (Spring 2019)

- Blind, randomized classroom-based experiment with 64 students in Spring 2019; Group A assigned to do a tutorial on DC superposition in Circuit Tutor and problems on DC source transformations in WileyPLUS as part of one homework assignment; Group B assigned to do the reverse
- WileyPLUS problems selected to correspond as closely as possible in number and type to those in Circuit Tutor, from problems in Irwin & Nelms textbook used in the course; unlimited attempts allowed
- Both groups encouraged to view examples (in Circuit Tutor or textbook, depending on system assigned, and to view videos available in WileyPLUS or Circuit Tutor on these topics
- Post-test to assess learning consisted of one 12-point problem on each topic as part of a 100-pt. midterm exam; survey administered for extra credit (67% response rate); problems taken from a different textbook
- Using open-coding to analyze the qualitative data for those who preferred Circuit Tutor (N = 33), 39% reported that Circuit Tutor walked them through the problems and allowed them to follow along, 23% liked the examples given, 21% liked that the system was interactive, 10% liked the immediate feedback, and 6% liked how they solved the problems
- For those who preferred WileyPLUS (N=9), open-coding the qualitative responses revealed that 67% said it was because they could make more mistakes, 22% said that they liked working the problems by hand, and one person (11%) said that it was easier to navigate

Survey Results—Student Preferences



Survey Results—Sample Student Comments

Comments from those favoring Circuit Tutor (N = 33):

- *Because the questions are broken down into several steps, I find Circuit Tutor to be more helpful for developing a systematic approach for problem solving.*
- *If I could not figure out a Circuit Tutor problem, the walk through at the end would usually clear things up. WileyPLUS had none of that, so I felt like I was on my own.*
- *Circuit Tutor allows for a more rapid feedback to where the mistakes you have made and how to learn from them. Wiley is much less kind with its feedback and precision that is needed for the answer is less than ideal.*
- *Circuit Tutor gives me better results in terms of information retention due to its educational game-like format.*
- *I enjoyed Circuit Tutor because it is interactive and forces you to visualize the concepts as you modify the circuit and solve the problem, which aides [sic] in overall comprehension and understanding.*

Comments from those favoring WileyPLUS (N = 9):

- *I preferred WileyPLUS because I prefer to work out the circuit by hand. I find myself making mistakes on paper that I can easily erase and correct, but when I make them on Circuit Tutor I have to start a new problem when this happens. Writing things down also helps me remember how to do things better in the future, and when I do them on Circuit Tutor I have difficulty remembering what I did when I advance to a new problem.*
- *I preferred WileyPLUS because I was allowed to make mistakes without being penalized and having to start over.*

Usage Data and Survey Results

- A total of 23 different tutorials are now available, covering identification of series & parallel circuit elements (including the case when terminals are present); simplification of resistors, inductors, capacitors, and general impedances in series & parallel, including complicated, multi-step sequences; both DC and AC steady-state node and mesh analysis, including full solutions of those problems; DC single node-pair and single loop analysis including voltage & current division; superposition, source transformations, and Thévenin/Norton equivalent circuits in both DC and phasor domains; the mathematics of direct and inverse Laplace transforms; construction of Bode plots from transfer functions; and interactive sketching of waveforms such as current, voltage, power, and energy as a function of time for general electrical properties and for inductors and capacitors
- 34 YouTube videos illustrating the solution of problems in many of the tutorials are now available at https://www.youtube.com/channel/UCnn_0DTFVFpiorlWiTTUVvg
- A total of over 6000 students in 146 class sections taught by 55 distinct instructors at 13 different colleges and universities of widely varying types have used the system to date, usually as required homework. Institutions have included Arizona State University, University of Notre Dame, University of the Pacific, Morgan State University, University of Texas at El Paso, Florida Agricultural and Mechanical University/Florida State University, Auburn University, Messiah College, North Carolina A&T State University, Hampton University, South Mountain Community College, Chandler-Gilbert Community College, and Glendale Community College
- In surveys at time of module completion, students were asked to rate the tutorial as "very useful," somewhat useful," "not very useful," or "a waste of time." For the year Spring 2015-Fall 2015, the responses in each category (combining all tutorials) were 65%, 26%, 4%, and 5%, respectively, for a total of 91% favorable (very or somewhat useful)

Effects on Student Learning and Preferences

TABLE I. SUMMARY OF RANDOMIZED, BLIND EXPERIMENT COMPARING THE TWO TUTORIAL SYSTEMS.

	Superposition		Source Transformation	
	Circuit Tutor	WileyPLUS	Circuit Tutor	WileyPLUS
Group	A (N=32)	B (N=32)	B (N=32)	A (N=32)
HW Completion Rates	94%*	75%	69%	88%†
HW Score (0 to 33)	29.22 (9.52)	30.86 (5.32)	23.96 (14.06)	31.43 (4.93)*
Midterm Exam Item Score (0 to 12)	6.59 (4.49)	6.29 (2.80)	6.71 (4.58)	5.91 (2.41)

Note: †$p < 0.10$; *$p < 0.05$. Values in parentheses are standard deviations.

Conclusions

- Our step-based tutoring system has been extended to cover topics that involve an intricate sequence of steps including multiple edits to a circuit diagram and ultimately writing equations for it.
- Detailed feedback is provided to students at each step so that they do not waste time continuing to analyze a circuit after making a fatal error in prior stages
- Automated problem and solution generation is employed to provide each student with an unlimited supply of both problems and fully worked and explained examples
- The new system is at least as effective as a mature commercial system in terms of post-test scores (based on the limited evaluation used here), and is strongly preferred over the commercial system by students for both of the new tutorials
- The system is currently being improved by adding introductory interactive, expository tutorials on these subjects and by extension to new topics including Thevenin/Norton equivalent circuits
- Further evaluations are in progress in Fall 2019

Reference

1. K. VanLehn, "The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems," *Educat. Psychologist*, vol. 46, no. 4, pp. 197-221, 2011.

For Further Information or to Use this Free Software in Your Classes

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Acknowledgments

This work was supported by the National Science Foundation through the Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics Program under Grant Nos. 1821628, 1044497, and 1323773. We thank J. Aberle, G. Abousleman, M. Ardakani, J. Blain Christen, S. Chickamenahalli, S. Dahal, A. Ewaisha, R. Ferzli, G. Formicone, S. Goodnick, R. Gorur, O. Hartin, S. Jayasuriya, G. Karady, R. Kiehl, H. Mao, B. Matar, A. Maurer, D. Meldrum, B. Moraffah, C.-Z. Ning, S. Ozev, L. Sankar, A. Shafique, W. Shi, D. Shin, M. Tao, C. Tepedelenlioglu, T. Thornton, G. Trichopoulos, D. Vasileska, C. Wang, Y. Weng, M. Wong, Yu Yao, Hongbin Yu, and Hongyu Yu for using our software in their sections of EEE 202 at ASU. We thank W. Thompson II and Y. Astatke for using our software at Morgan State University, H. Erives-Contreras for using it at University of Texas at El Paso, P. Andrei for using it at Florida A & M University/Florida State University, H. Underwood, R. Fish, and D. Pratt for using it at Messiah College, J. D. Irwin for using it at Auburn University, J. Ross and H. Xu for using it at University of the Pacific, V. Gupta for using it at the University of Notre Dame, A. Holmes for using it at the University of Virginia, G. Gilmore for using it at North Carolina A&T State University, O. Nare for using it at Hampton University, and T. Frank and B. Matar for using it at Glendale, South Mountain, and Chandler-Gilbert Community Colleges. We thank Don Fowley of John Wiley & Sons, Inc. for supporting the project.