Interactive Tutorial System for Linear Circuit Analysis: Impact on Learning and Novel Tutorials

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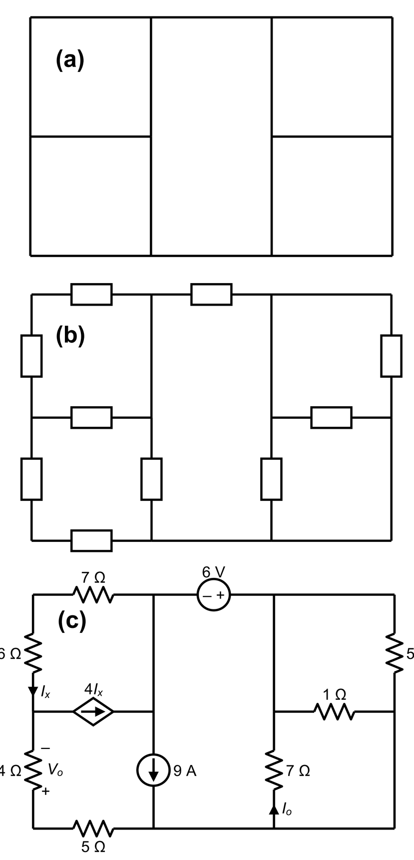
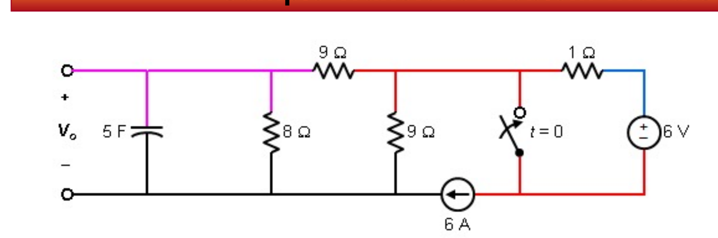
Introduction

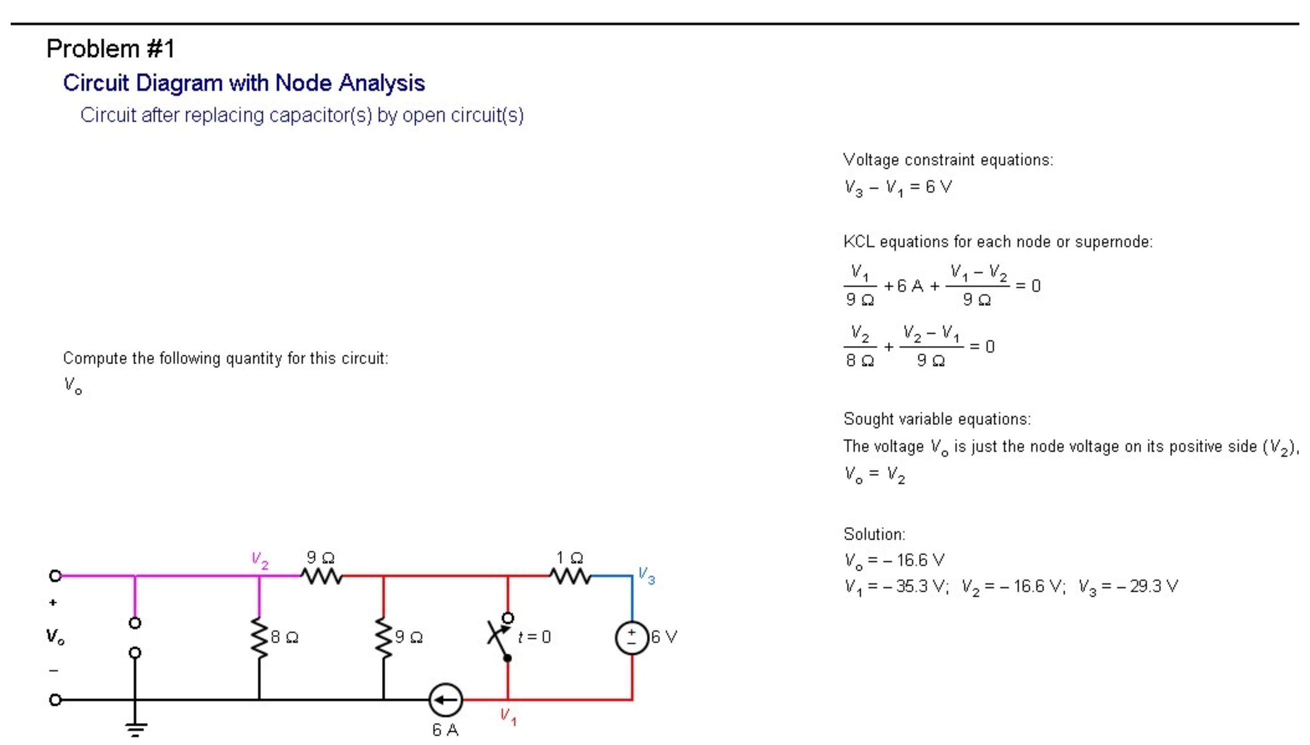
- Linear circuit analysis is a foundational topic for electrical engineering students and frequently comprises the exposure to electrical topics for non-electrical engineers. Increasing success in this course is therefore important to improving graduation and retention rates
- This approach involves random problem generation using special algorithms (varying the structure of the circuit, not just element values), and automatic generation of fully worked and explained solutions using normal textbook methods (rather than numerical approaches as in PSPICE, etc.)
- This system provides step-based tutoring, where every phase of a student's work is immediately checked for accuracy using special interfaces to accept re-drawn or edited circuit diagrams, equations (using special template-based interfaces), interactively sketched waveforms as a function of time, simplified equation and matrix entry forms, etc.
- The well known advantages of studying worked examples in the early stages of learning[1,2] are exploited in this system, where the examples are designed to be isomorphic to the problems
- Typical misconceptions and qualitative skills are targeted, such as identification of elements in series and parallel
- The software is adaptive to the needs of individual students, providing more or less practice and explanation in each case as needed by individual students

Three-step Process for Circuit Generation

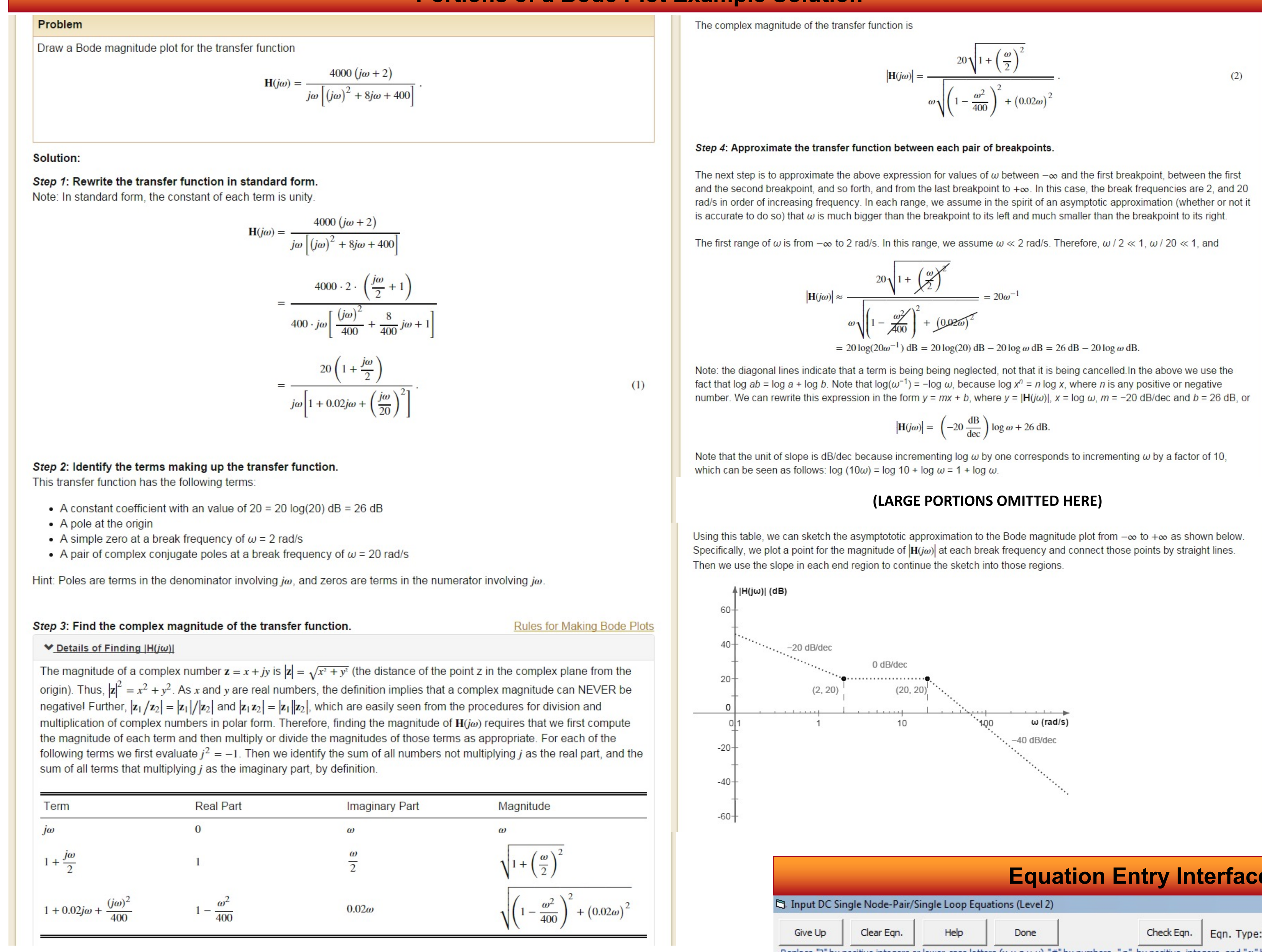


Sample Transient Problem with a Switch and Solution at $t = \infty$

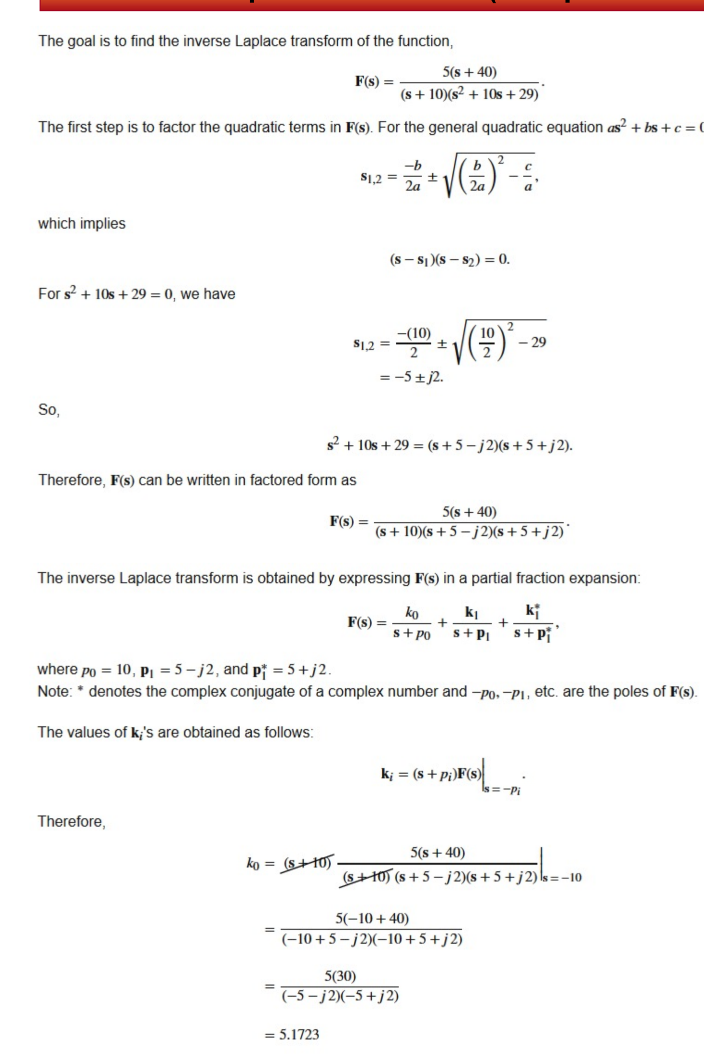




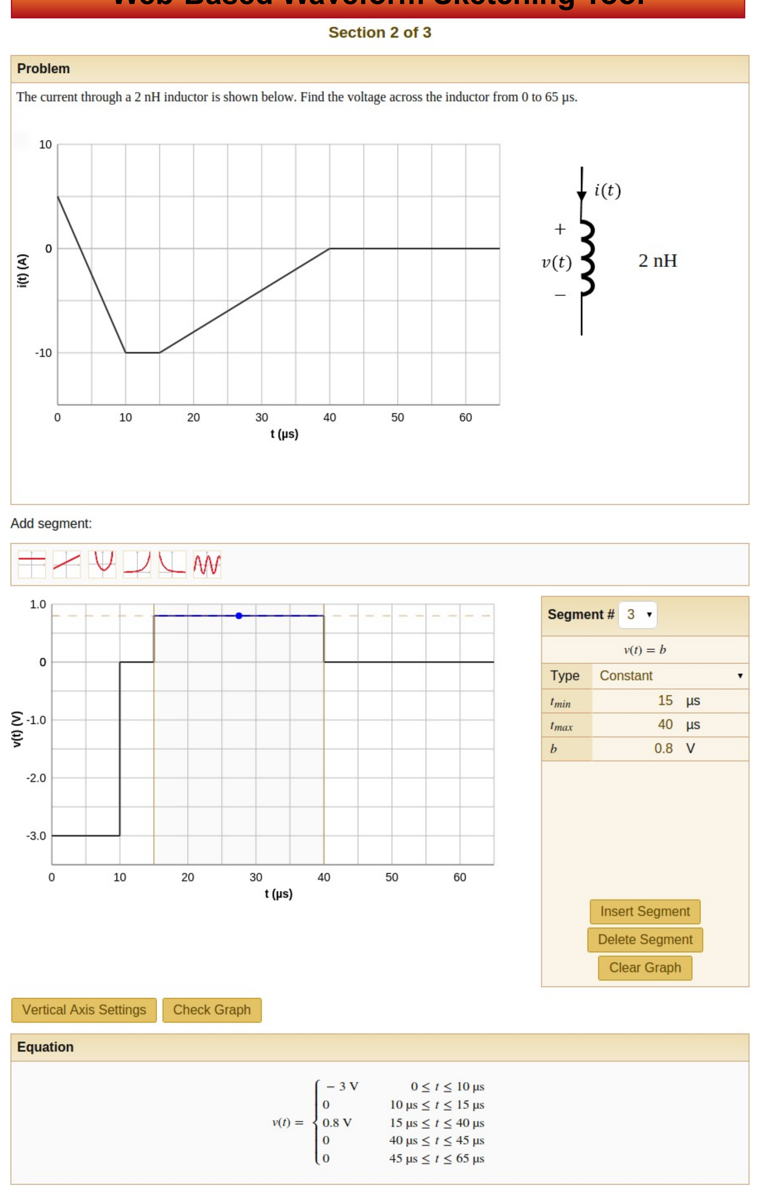
Portions of a Bode Plot Example Solution



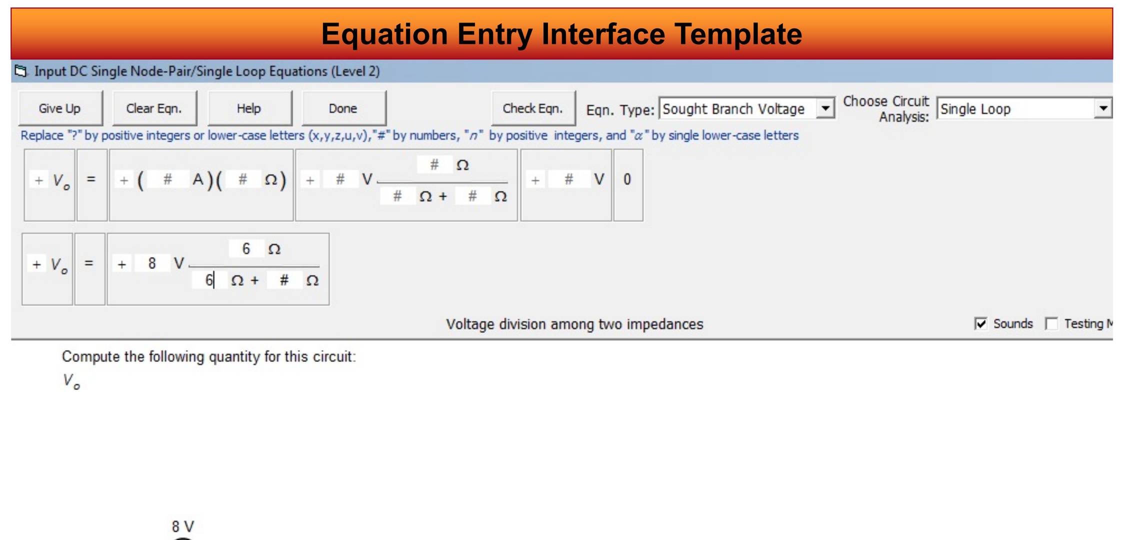
Inverse Laplace Transform (Computer-Generated)



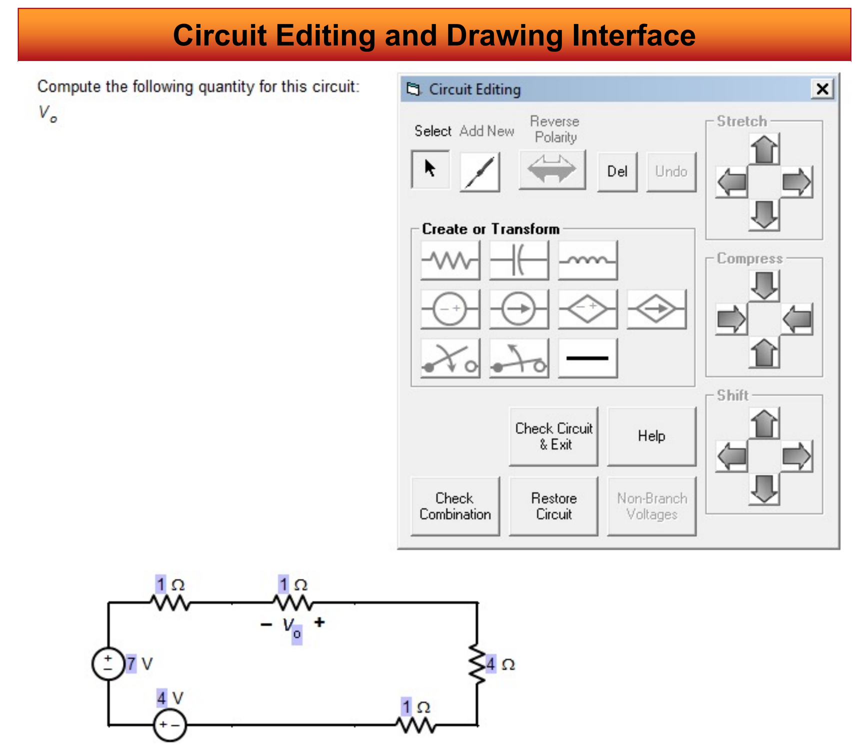
Web-Based Waveform Sketching Tool



Equation Entry Interface Template



Circuit Editing and Drawing Interface



Usage Data and Survey Results

- A total of 18 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; 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
- A total of over 2860 students in 71 class sections at 10 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, Auburn University, Messiah College, North Carolina A&T State University, University of Virginia, 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 most recent 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).
- Ratings from a more detailed, anonymous survey administered at the end of each semester were also generally favorable as shown in Table II

Comparison with Publisher-Based Homework System (Fall 2015)

- Prior trials of this system showed a large, statistically significant advantage over paper homework (e.g., Cohen *d*-value, based on difference of post-test scores of 1.21 σ in a laboratory-based trial in Fall 2013 with $p < 0.05$) and higher assignment scores and student preferences over a publisher-based system in Fall 2014 ($p < 0.008$ with an effect size of $d = 0.41\ \sigma$)
- A second randomized, controlled classroom-based evaluation was conducted in Fall 2015 (similar to the one in Fall 2014), where students were randomly assigned to either A) use Circuit Tutor for nodal analysis, and the publisher system (denoted "System X") for mesh analysis; or B) the opposite. On the assignment due date, a post-test (quiz) was given in class on both topics to the total of ~70 students (not performed in Fall 2014). An anonymous survey was also administered asking them to compare Circuit Tutor to System X.
- Students using Circuit Tutor had a statistically significant higher post-test score than those using System X on node analysis (Table I), with [t(64) = 3.09, $p < 0.05$] with an effect size (Cohen *d*-value) of 0.72σ. For mesh analysis, the difference was not statistically significant [t(64) = 0.88, p = 0.38], which may reflect the fundamentally easier nature of that topic (both groups had relatively high averages).
- Large majorities also preferred Circuit Tutor over System X and felt that it taught them more effectively (Table I).
- A typical student comment was "I liked Circuit Tutor more because I could do a ton of problems. I liked that even if I couldn't figure it out, I could 'give up'; and it would thoroughly explain how to do everything so I could understand what I did wrong and then do a new problem and try to get that right. I seem to retain more of the content when I am doing this one. I have trouble with [System X] because, if I have trouble with a problem, the hints do not explain what I am doing wrong. It's really frustrating because I could be 2 or 3 wrong attempts in and I do not know what I'm doing wrong."

Effects on Student Learning and Preferences

Table I. Results of Classroom-Based Experiment in Fall 2015.

System used	Circuit Tutor	System X
Mean post-test score–node analysis (std. dev.)	72%(24%)	49%(33%)
Mean post-test score–mesh analysis (std. dev.)	71%(25%)	65%(31%)
Mean node/mesh HW score	79%	69%
Preferred system in question	86%	9%*
Felt system in question taught more effectively	94%	3%*

*Remaining students rated both systems equal

Software Survey Results (End of Semester)

Table II. Percentage of Favorable Scores on End-of-Semester Survey by Institution

Institution	Useful & well designed	Appropriate. difficulty & coverage	Prefer to conventional homework	Overall	*N*
Arizona State Univ.	80.0%	78.6%	78.5%	79.0%	841
Morgan State Univ.	78.1%	70.1%	79.5%	75.9%	56
Univ. of the Pacific	69.4%	71.1%	53.3%	64.6%	45
Messiah College	87.1%	91.4%	82.8%	87.1%	58
Univ. of Notre Dame	91.8%	91.9%	87.9%	90.5%	31
All (combined)	80.1%	78.7%	77.8%	78.9%	1031

Conclusions

- Recently added features include automatic generation of voltage and current division equations; new tutorials featuring interactive waveform sketching of electrical quantities; Laplace and inverse Laplace transform tutorials where students interactively complete exercises using a template-based system; and problem and solution generation involving superposition and switches for transient circuits
- Over 2860 students have used the software to date in 71 class sections at ten different colleges and universities of various types
- Student satisfaction has been high at various institutions and students strongly prefer the system to a commercial, publisher-based system
- A new controlled, randomized classroom-based trial in Fall 2015 showed a statistically significant advantage of 0.72σ for nodal analysis taught by Circuit Tutor as compared to a commercial, publisher-based system; results for mesh analysis were not significantly different

For Further Information or to Use this Software in Your Classes

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