Recent Progress in Step-Based Tutoring for Linear Circuit Analysis Courses

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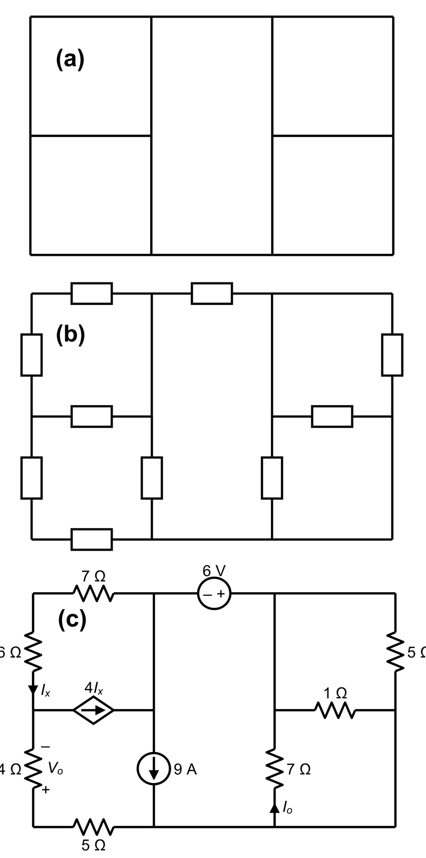
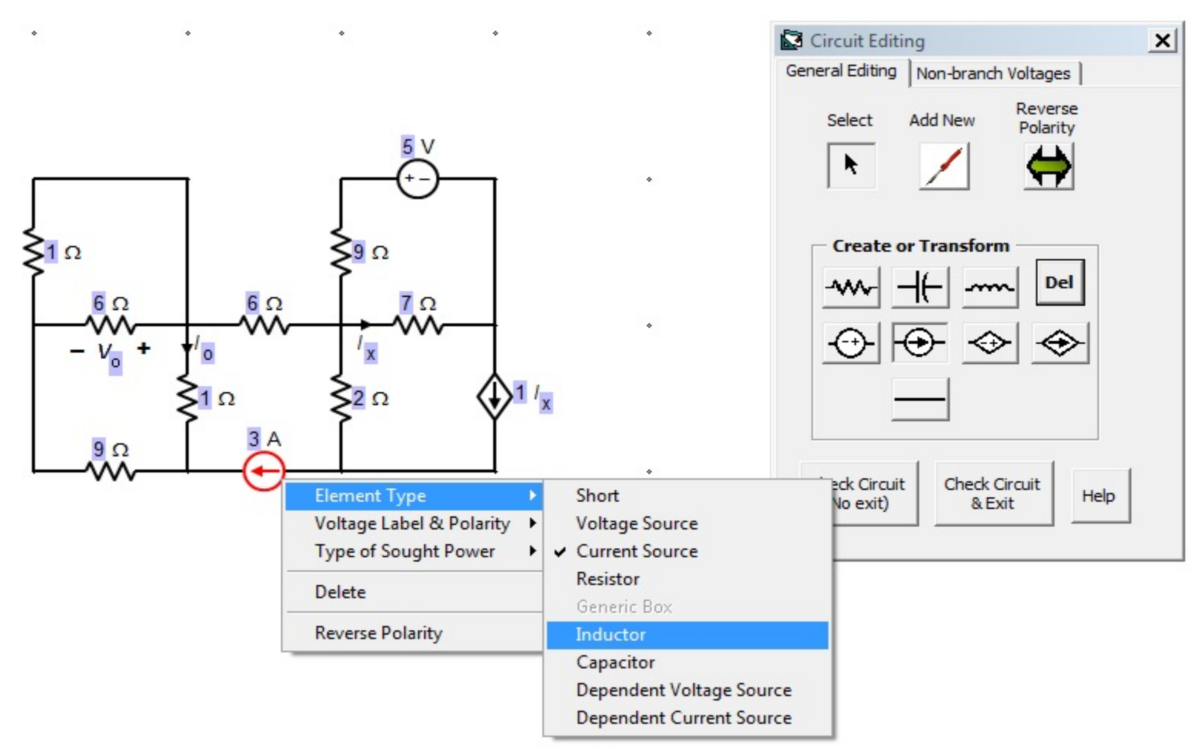
Introduction

- Success in widely-taught introductory engineering courses such as linear circuit analysis can have a strong impact on retention and graduation rates
- Conventional paper homework provides delayed and sometimes inaccurate feedback, hampering student learning and progress; most existing publisher-based web sites provide only answer-based algorithmic tutoring exercises, with little ability to identify or correct the sources of student errors
- We are developing more effective, step-based computer-aided tutoring systems that accept and evaluate each step of a student's work, providing immediate feedback and corrections
- A special feature of our system is automated problem (and solution) generation, so that every student receives different problems, and can be given a fundamentally new problem of the same type any time they need to be shown the detailed solution; unlimited examples are also available, which are isomorphic to the exercises
- Special exercises in our system target typical student misconceptions and crucial areas of difficulty, such as identifying circuit elements in series or in parallel
- Our system adapts to needs of individual students, providing as much or as little practice as needed on any given topic

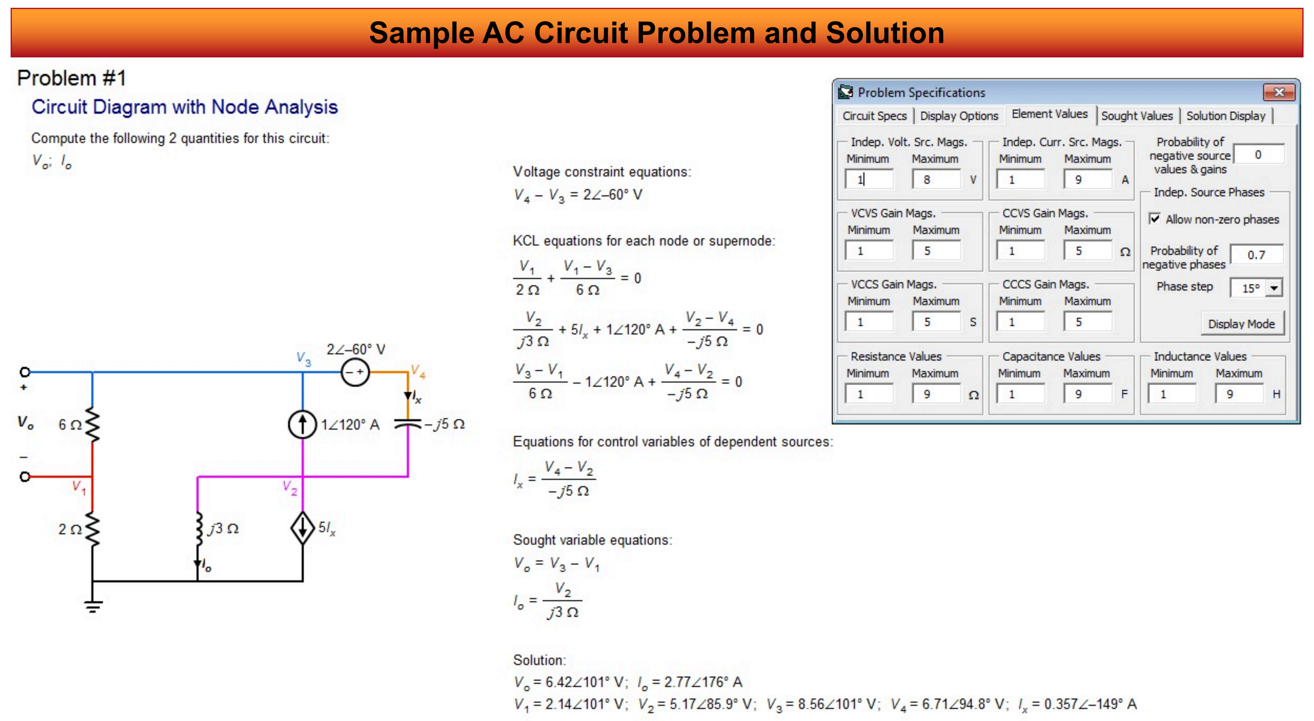
Three-step Process for Circuit Generation



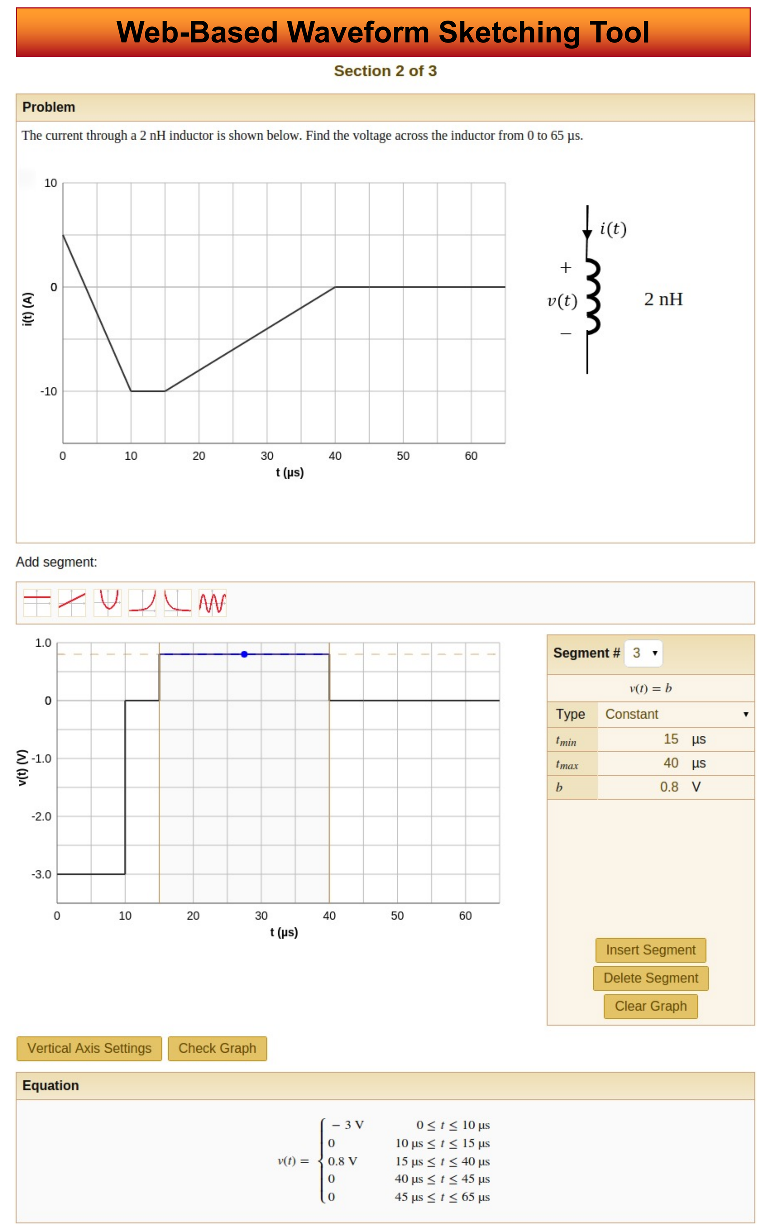
Circuit Editing and Drawing Interface



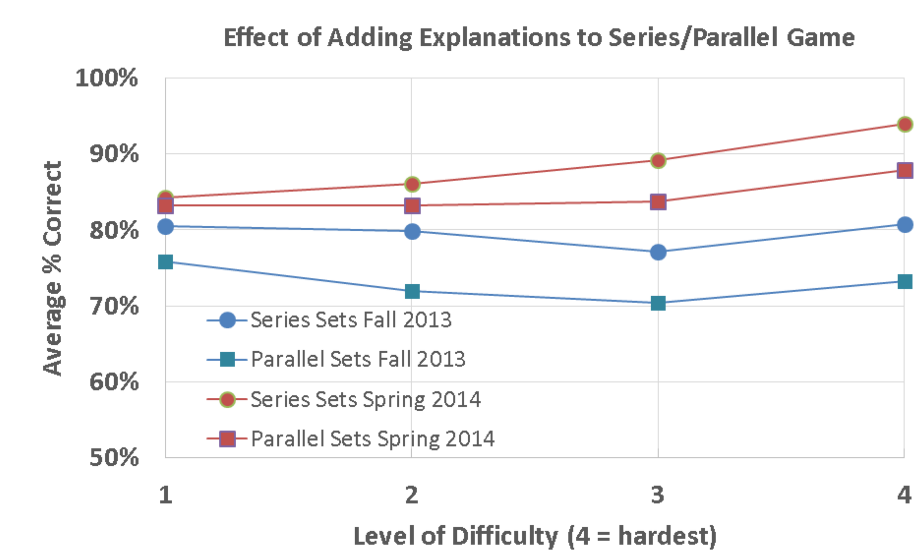
Sample AC Circuit Problem and Solution

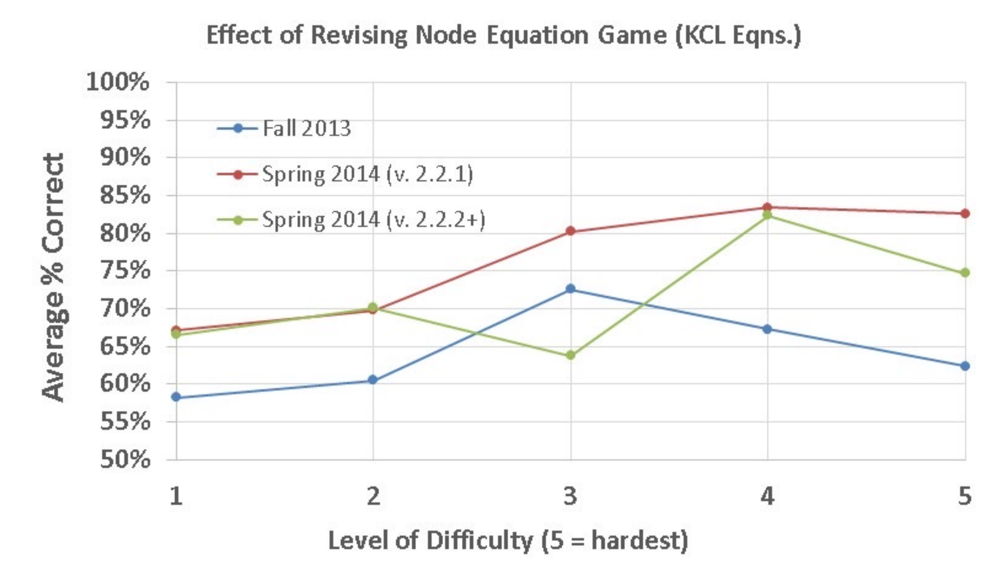


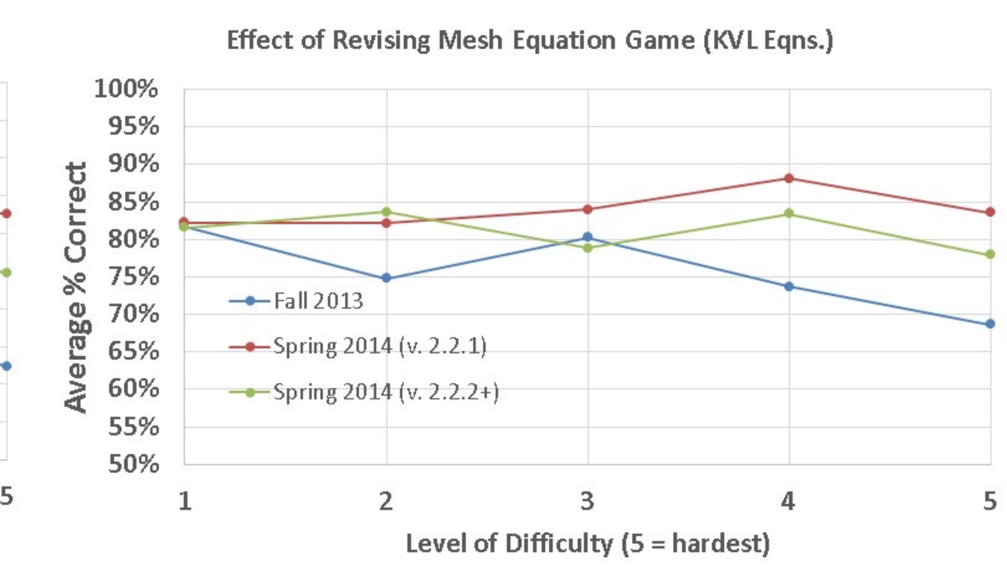
Web-Based Waveform Sketching Tool



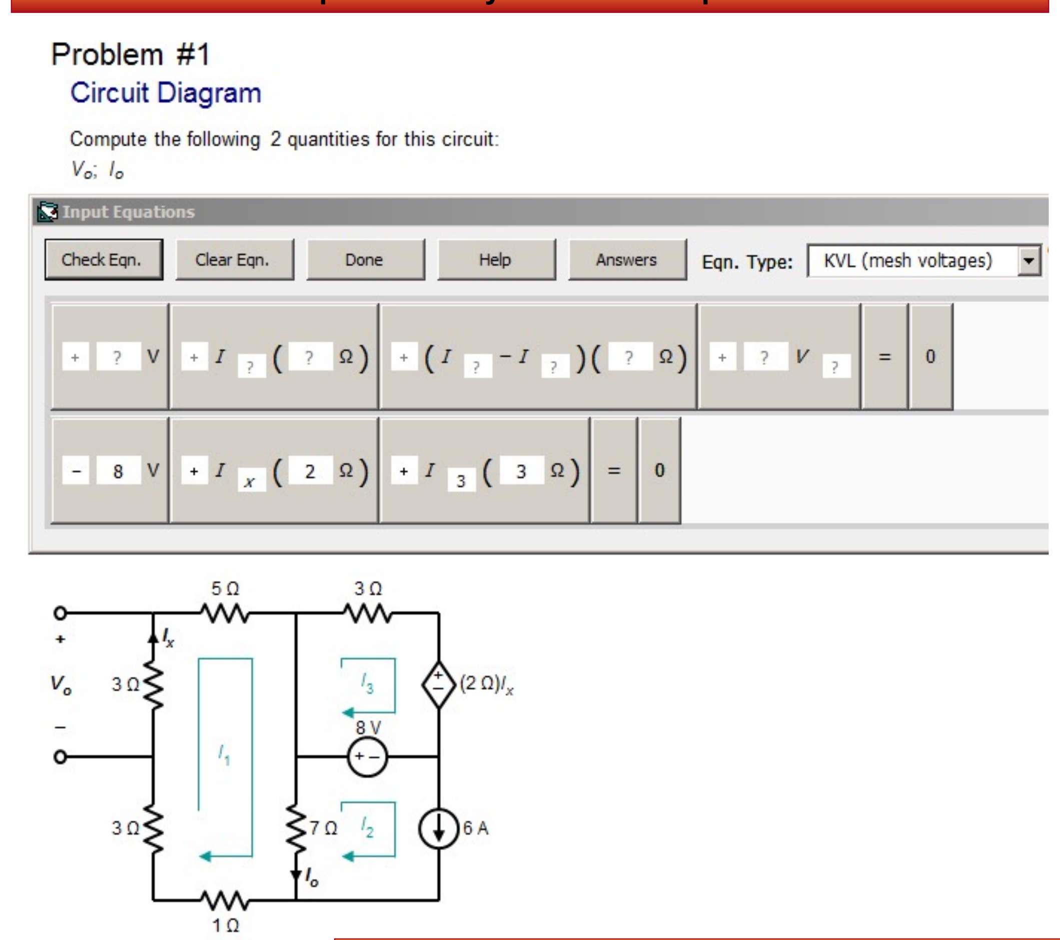
Refinement of Tutorials Based on Log Data: Effect on Student Accuracy



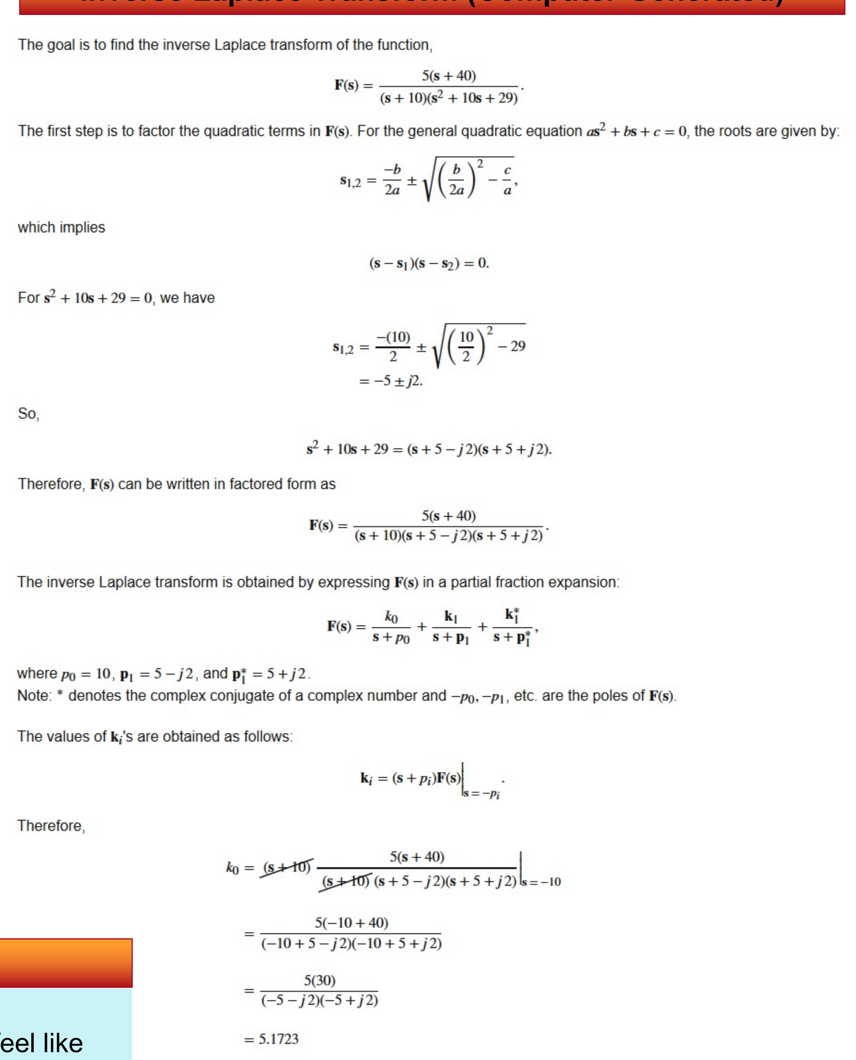




Equation Entry Interface Template



Inverse Laplace Transform (Computer-Generated)



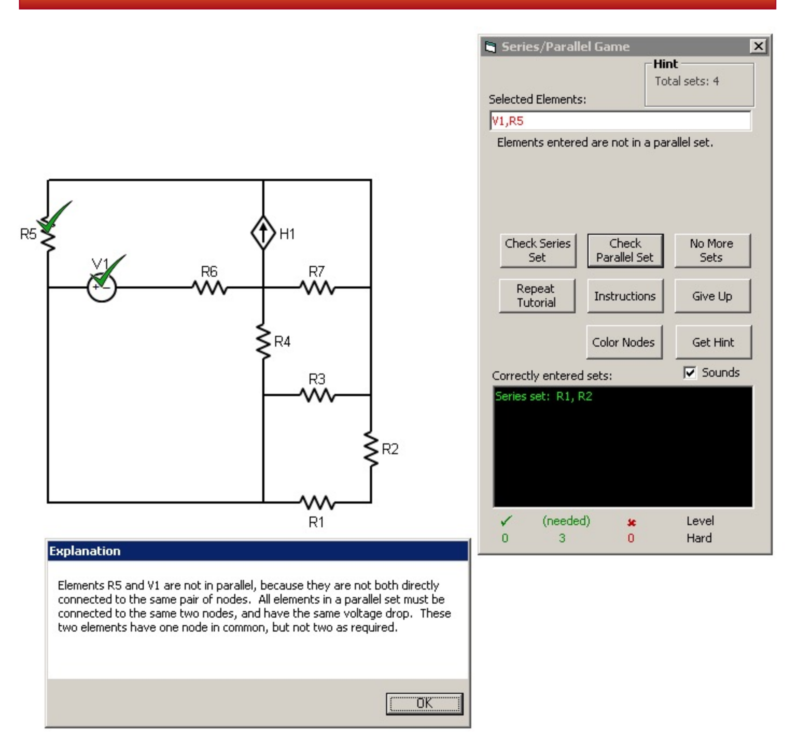
Usage Statistics

- A total of 15 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; and the mathematics of Laplace transforms
- A total of over 1950 students in 42 class sections at Arizona State University, University of Notre Dame, University of the Pacific, Morgan State University, Messiah College, South Mountain Community College, and Chandler-Gilbert Community College have used the system to date, usually as required homework exercises
- In surveys at time of module completion, ~96% of respondents said the tutorials were very or somewhat useful, and 70% said they were very useful
- Usage rates of 92-95% were achieved in at least six sections whose instructors required and encouraged use of the software, indicating that it has the potential to be quite high.
- Student comments were generally very favorable (Table I)

Table I: Student Comments (Fall 2014)

- **Series-Parallel Tutorial**
  I received a 0% on the pretest and a 100% on the post test. I feel like the program was extremely intuitive.
  I was pleased with it. The exercises had a good balance of being challenging enough without being over the top difficult.
  I thought this was very helpful in learning what was in series and what was in parallel. Also, I thought that starting with hints was useful to learn the patterns of the nodes. Very much appreciated the explanations for the answers.
- **Series-Parallel with Terminals Tutorial**
  The best thing I liked about the game was the fact that it explained why my incorrect responses were incorrect. It provided an explanation as to why an answer was wrong.
  No areas I would suggest for improvement. I thought the terminals exercise was particularly useful as it is something I have never considered before. Very good.
  These games are great. This my first introduction to circuits and im loving it.
- **Inductor/Capacitor Simplification Tutorial:**
  I learn a lot from my mistakes. A great game to practice parallel and series on inductors and capacitors
  I love the whole baby step process where it starts you off with color coded simple circuits, and it progressively gets harder and harder. It gives you feedback on problems you get wrong and you can see what you are doing wrong and how to correct yourself.
- **DC Node Equations Tutorial**
  Amazing. Simply Amazing. This helps so much to get the concept of node and mesh analysis better than writing out equations on paper. My ability to do this type of analysis now will be much better because the concepts are so easy to understand using this type of circuit and format. Thanks!
- **DC Mesh Equations Tutorial**
  nice guide, helps more than pen and paper hw.
  This helped me study for the exam better.
- **DC Node Solutions Tutorial**
  Harder at harder levels. I like that becuase it is easy at easy levels. I felt challenged but i also learned.
  Excessively pedantic, and tedious.
- **AC Nodal Equations Tutorial**
  I've said before, withouth this circuit tutor I would probably be having a harder time in this class.
  These structured and very approachable exercises are, in my opinion, superior to [name of publisher-based system also used in class]. Keep up the good work.
  hard, but gooood
- **AC Mesh Equations Tutorial**
  Circuit Tuitor is one of the best learning tools I've used. I despise [name of publisher-based system also used in class], but I would (and did) do the Circuit Tuitor activites in order to increase my understanding.
  Get it on Mac or the internet! Otherwise it is really good and incredibly helpful.

Series/Parallel Identification Game



Conclusions

- Circuit Tutor now features an improved, highly capable graphical circuit editor, the ability to generate and solve AC circuits using phasor analysis in addition to DC circuits, and a fully developed web-based waveform sketching tool that can assess the correctness of student drawings.
- Nearly 2000 students have used the software to date in over 40 class sections at seven colleges and universities
- Student satisfaction has been high, with over 96% of students rating the tutorials as "very useful" or "somewhat useful" for learning the topics (70% said "very useful)
- In a controlled, randomized laboratory-based study, a significant effect size of 1.21 σ was obtained in comparison to doing conventional textbook homework for the same time period, on two separate topics
- Further optimization and expansion of the tutorials is in progress, using a large quantity of data from log files collected on student activity in the system

Comparative Study with Traditional Homework

- To provide a rigorous comparison of the learning effectiveness using our software, we carried out a randomized, controlled, laboratory-based study with a careful evaluation of statistical significance and effect size
- Subjects were student volunteers currently enrolled in the relevant course, or who had completed it in the last year; they were randomly assigned to experimental or control groups
- All subjects took paper-based pre- and post-tests covering a qualitative and a quantitative topic, namely identification of series-parallel connections and writing DC node equations
- The experimental group used two of our software tutorials for a total of one hour (25 and 35 min., respectively); the control group worked paper-based textbook problems for the same time
- The experimental group had a ~10X larger learning gain than the control group, with an effect size (Cohen *d*-value, based on difference of post-test scores) of 1.21 σ, considered to be very large, where $t(19.7) = 3.303$, $p < 0.05$ (see Table II)
- The experimental group also had a significantly higher score on the Instructional Materials Motivation Survey (IMMS) of Keller with an effect size of $d = 0.91\ \sigma$ ($p < 0.05$)

Effects on Student Learning

Table II. Learning Gains in Randomized, Controlled Laboratory-Based Study

	Exptl. Condition	Pre-Test Score	Post-Test Score	Gain
Average	Textbook*	58.6	61.6	2.9
Std. Dev.	Textbook	25.3	28.0	14.1
Average	Software**	57.8	86.4	28.6
Std. Dev.	Software	22.1	11.5	14.9
Std. Dev.	Pooled	23.0	20.5	14.1

*16 users. **17 users.

For Further Information or to Use this Software in Your Classes

Contact Brian J. Skromme, School of Electrical, Computer, and Energy Engineering, Arizona State University, Box 875706 Tempe, AZ 85287-5706 Phone: (480) 965-8592 FAX: (480) 965-8118 e-mail: skromme@asu.edu

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