Expansion and Evaluation of a Step-Based Tutorial Program for Linear Circuit Analysis

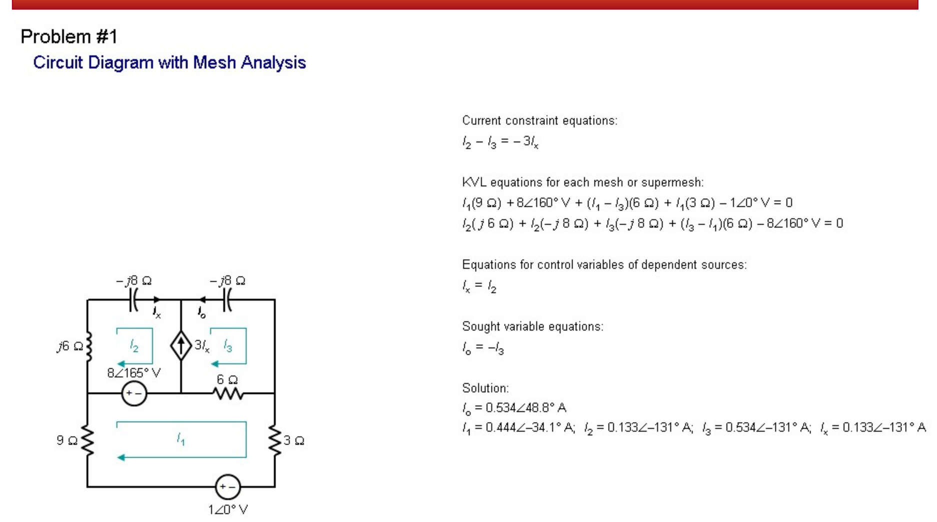
B. J. Skromme[a], P. J. Rayes[a], B. Cheng[a], B. E. McNamara[a], A. S. Gibson[b], A. Barrus[b], J. M. Quick[b], R. K. Atkinson[b], Y.-F. Huang[c], and D. H. Robinson[d]

[a]School of Electrical, Computer, and Energy Engrg., Arizona State University, Tempe, AZ 85287-5706
[b]School of Computing, Informatics, and Decision Systems Engrg., Arizona State University, Tempe, AZ 85287-5706
[c]Department of Electrical Engineering, University of Notre Dame, Notre Dame, IN 46556
[d]School of Education, Colorado State University, Fort Collins, CO 80523

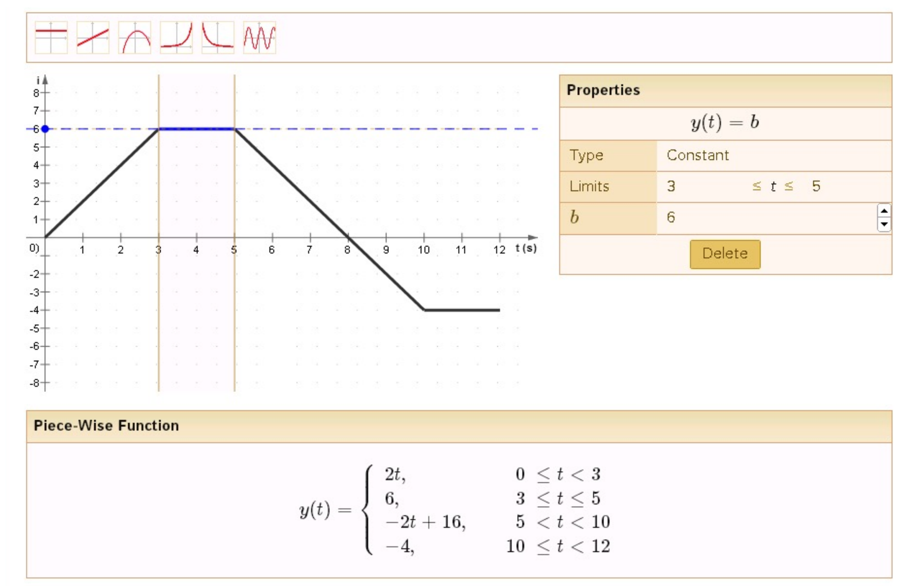
Motivation

- Linear circuit analysis is a very widely taught and important introductory class in many engineering curricula, and can have significant failure rates
- Many students struggle with such classes, due to a lack of detailed, rapid feedback and correction on their work, insufficient use of active learning strategies, and in our opinion, an insufficient systematization of and emphasis on the numerous principles that are necessary to solve a variety of problems successfully
- Our goal is to develop step-based computer-aided tutoring systems (in the form of "games") that systematically demonstrate and exercise the necessary skills in a way that offers student unlimited repetition until they individually achieve mastery of each topic. We are including special types of problems and targeted tutorial exercises to focus on developing qualitative understanding and on correcting typical student misconceptions
- Such an approach allows the software the flexibility to meet each individual student's variable needs, as opposed to the "one size fits all" philosophy inherent in conventional lecturing and textbooks
- This approach is also very well suited to potential applications in massive open on-line courses (MOOCs) and to other on-line instruction such as that in ASU's novel completely on-line bachelor's degree in electrical engineering (http://asuonline.asu.edu/online-degree-programs/undergraduate)

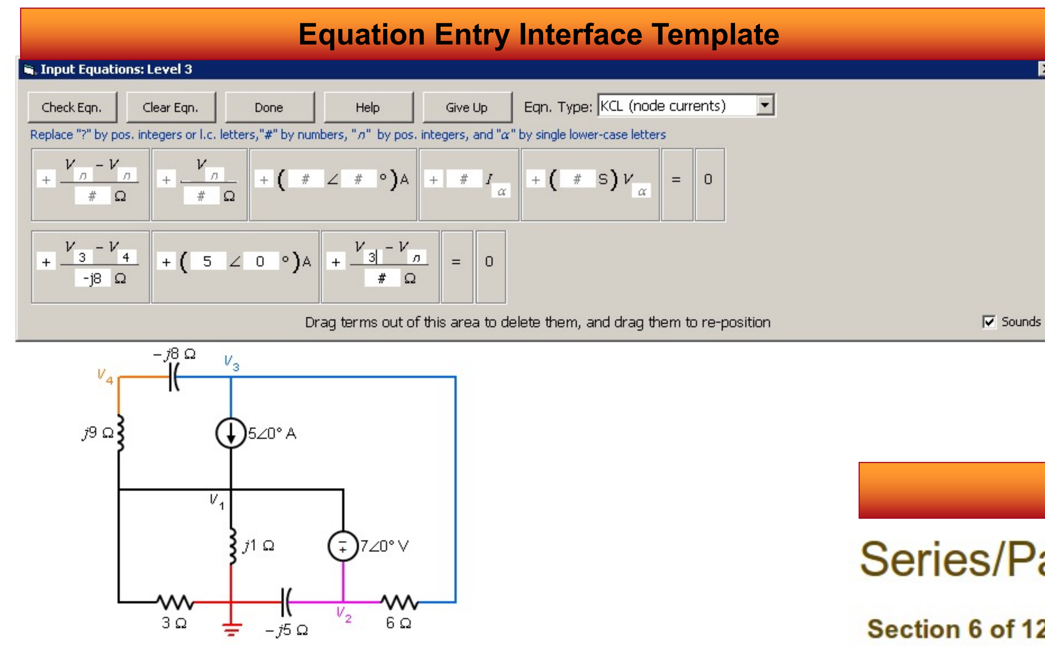
Sample AC Phasor Analysis Problem (New Feature)



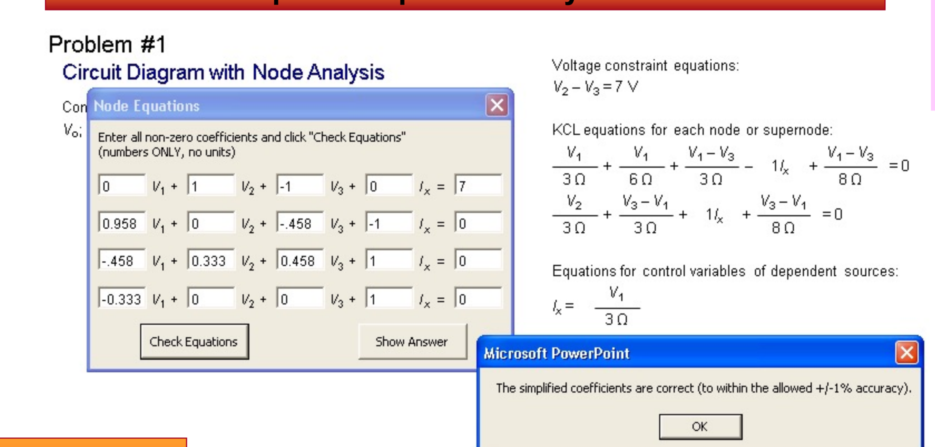
Web-Based Waveform Sketching Tool



Equation Entry Interface Template



Simplified Equation Entry Interface



Effects on Student Learning

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

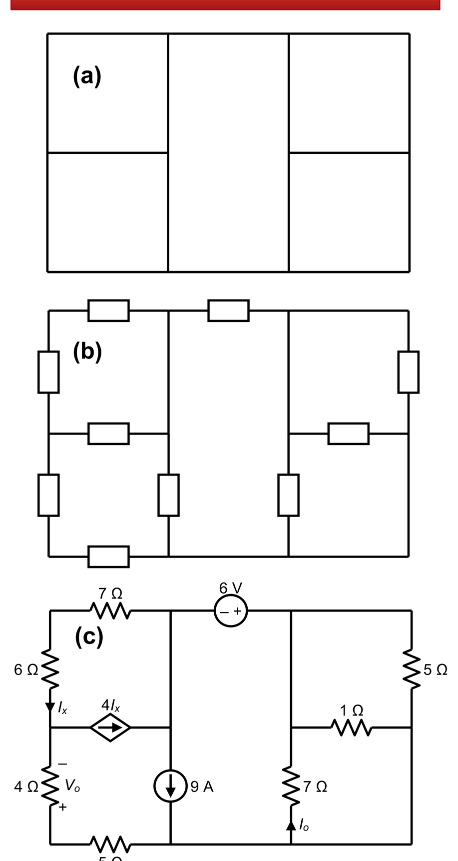
	Exptl. Condition	Pre-Test Score	Post-Test Score	Gain
Average	Textbook*	58.6	61.6	2.9
Std. Dev.	Textbook	25.3	28.0	14.1
Average	Software**	57.8	86.4	28.6
Std. Dev.	Software	22.1	11.5	14.9
Std. Dev.	Pooled	23.0	20.5	14.1

*16 users. **17 users.

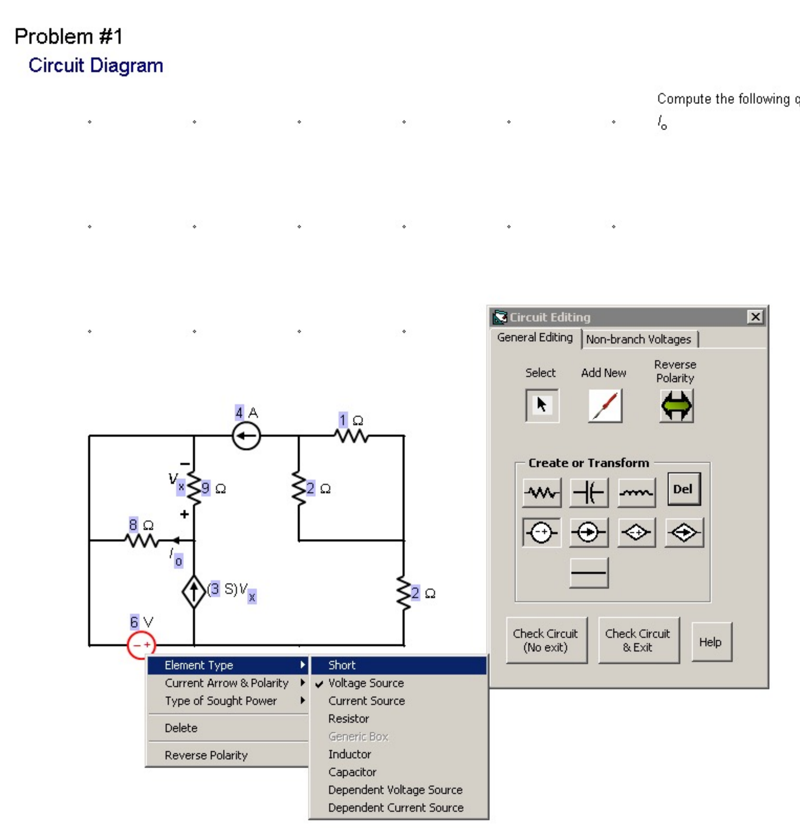
Assessment of Student Learning

- A randomized, controlled laboratory-based study was conducted using 33 paid student volunteers, all of whom were currently enrolled in EEE 202 or had completed it in the past year
- Students were given a pre-test and a post-test covering I) identification of series/parallel elements (qualitative topic) and II) writing node equations for a DC resistive circuit (quantitative topic), each lasting 25 minutes; two test forms A and B assigned randomly
- Control group was assigned to work textbook problems related to topics I and II for 25 min. and 35 min., respectively; experimental group used software tutorials on these topics for the same times (probably insufficient to complete the tutorials)
- Results are shown in Tables I and II; the learning gain for software users was about **10X higher** than for textbook users. Difference was statistically significant, $t(19.7) = 3.303$, $p < 0.05$. I.e., textbook users improved only from a high "E" to a low "D," whereas software users improved from a high "E" to a solid "B"
- Effect size, defined as difference in post-test scores divided by pooled standard deviation of post-test scores (Cohen's *d*-value), is $d = 1.21$, which is considered very large

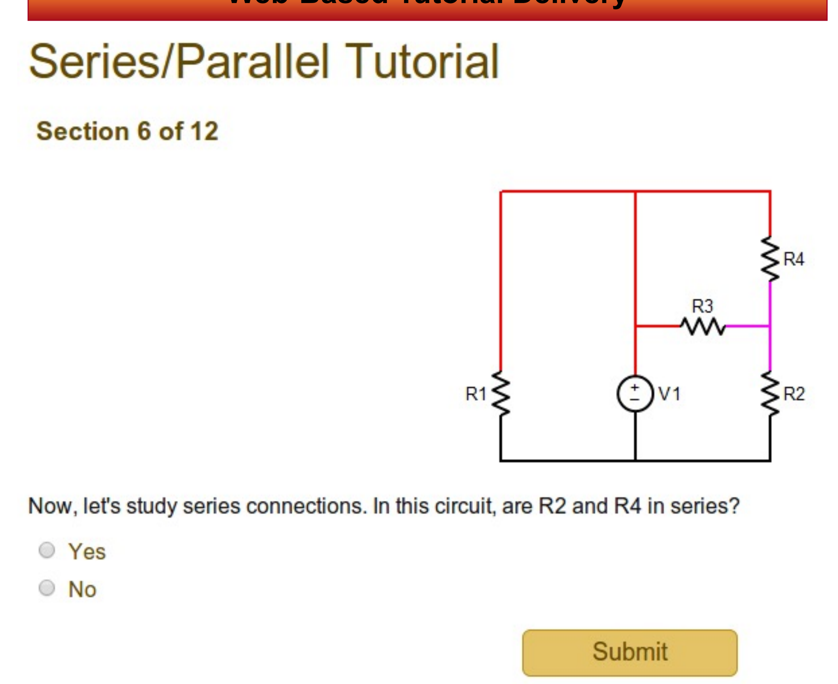
Three-step Process for Circuit Generation



Circuit Editing and Drawing Interface



Web-Based Tutorial Delivery



Student Comments

Series-Parallel Tutorial:

- This game helped out a lot with my understanding of parallel and series circuits. The colors of the nodes in the tutorial helped explain a lot also.
- Awesome! a little confusing at first but once you got the hang of it...
- At first i thought was really stupid and hard to use but then it ended up turning out pretty helpful to identify the series/parallel connections
- Great explanations, I look at elements in parallel completely different than I did before.
- The most important concept I was able to grasp was how to properly think of these circuits in nodes, thanks to the coloration of the easier levels. This was a huge leap, as now I can easily identify the circuit and think through problem
- It was fun and very interactive. I liked doing it a lot.
- I needed this repetitive practice to master the application of the concepts in class.
- Explain why some of the series connections work. I didn't understand why some of the less obvious ones were correct in the beginning.

Node Equation Tutorial:

- very informative and the examples shown are a great help in figuring out how the equations are calculated. One suggestion would be to have a short excercise explaining the process of how the equation is gotten
- I'm really glad that I was able to work on supernodes, as that's one of my bigger weaknesses about this. I also like the fact that dependent sources were worked on as well.
- I feel much better about nodal analysis and super nodes!
- This game was difficult. I enjoyed it though!

Mesh Equation Tutorial:

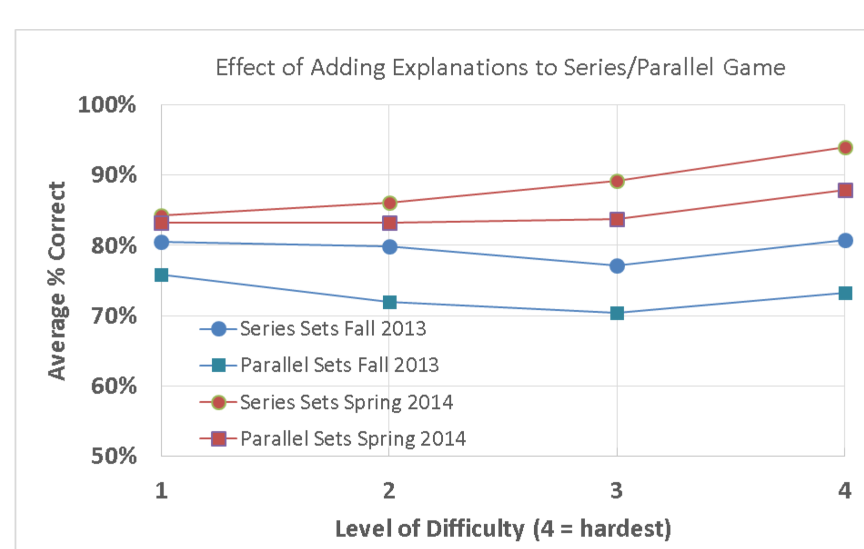
- I really enjoyed these exercises and wish that we had this tool for all of our lessons. This gave me the clearest explanations of what to do. Could have been slightly more detailed for the loops with dependant sources.
- As always, very helpful! A tutorial on what constitutes a supermesh and what has to be included would be nice.
- I like to have immediate feedback and the ability to go through the examples. this is a good product

Student Usage of Tutorials

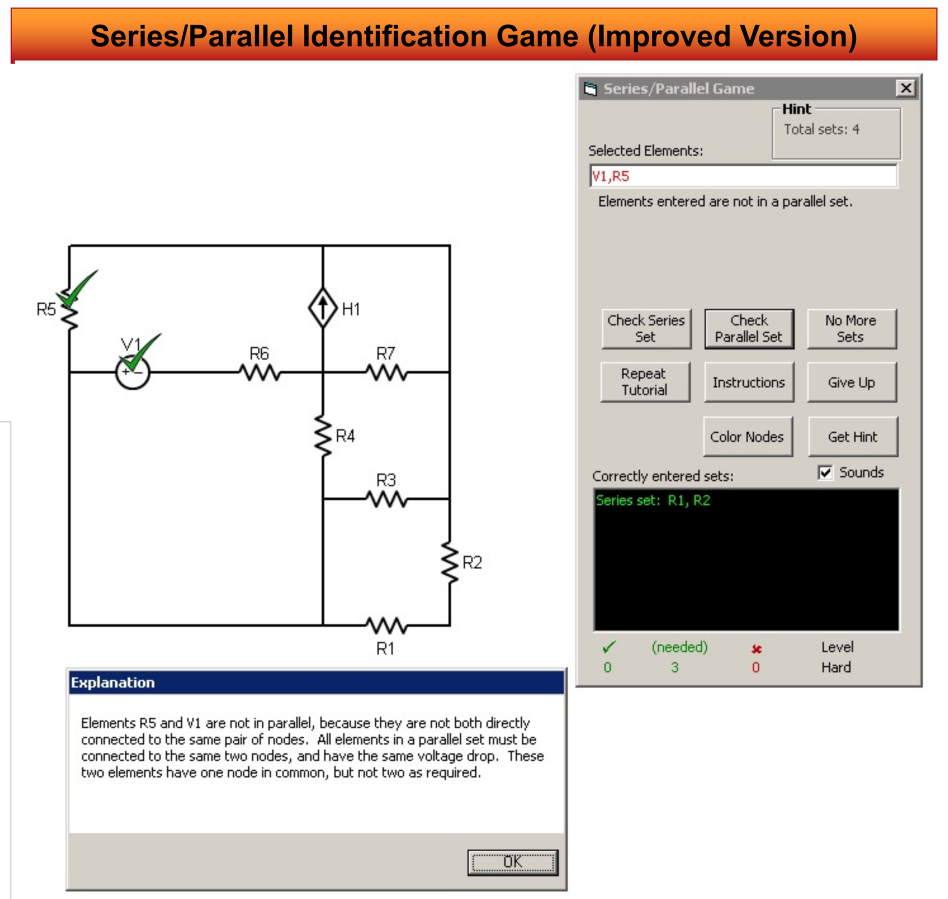
- In Spring, Summer, and Fall 2013 and Spring 2014 semesters, a total of 1020 students in 18 class sections at ASU, two community colleges, and the University of Notre Dame [42 students] used our software (defined as completing one or more of the three available tutorials). Over 80% of these students completed all three tutorials.
- During this period, we recorded over 193,000 log entries on our server while students analyzed over 28,000 different circuits, which provides a wealth of data to analyze.
- In the latest software version (Spring 2014), ~95% of respondents said it was very or somewhat useful, and 71% (overall) said it was very useful; results were somewhat higher for the equation writing than for the qualitative series-parallel module
- 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)

Iterative Refinement of Tutorials

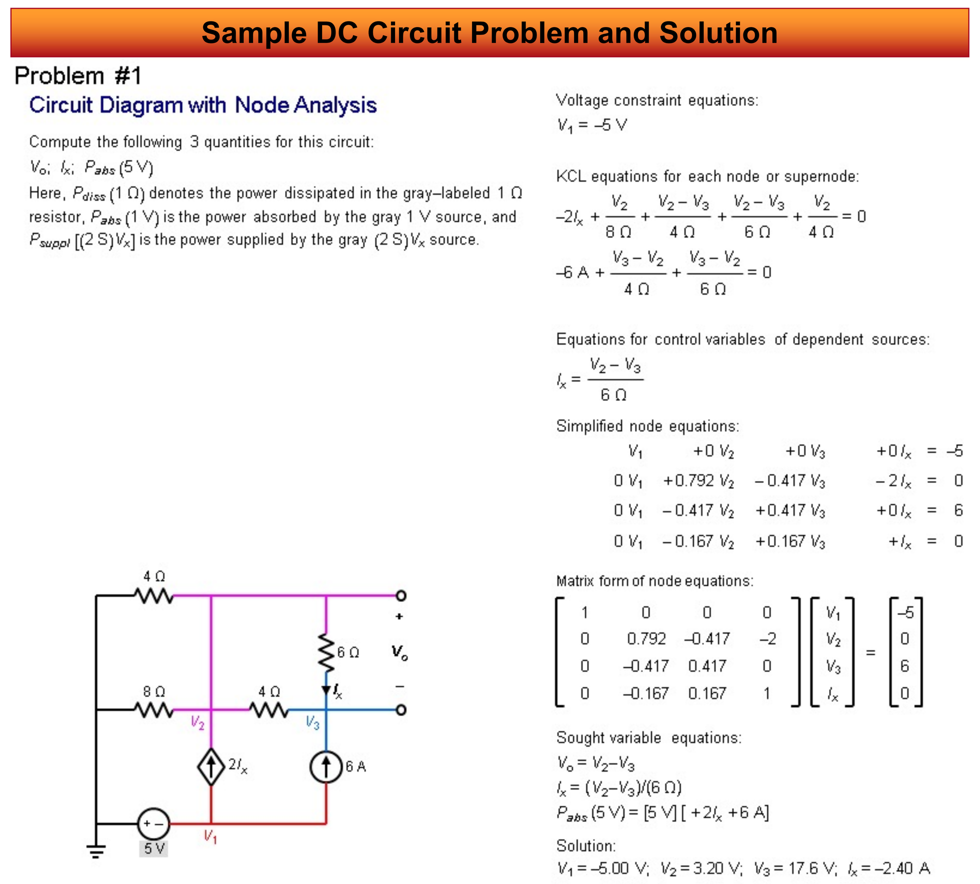
- Analysis of log file data showed that simply showing students the right answers when they made mistakes was not enough; the percentage correct declined or stagnated as they moved to more difficult problems in spite of additional experience
- The series-parallel, node equation, and mesh equation tutorials were refined in Spring 2014 to include detailed explanations of why the correct answers are correct; and in the series-parallel case, why incorrect answers were incorrect
- We also limited the number of wrong answers by forcing the students to "give up" and view the correct answers and optionally a detailed explanation when they made too many errors on a given problem
- The effect (shown below) was an increase in percentage of correct answers, that now <u>increases</u> with difficulty level and experience (as one would hope if they are really learning the material well!)



Series/Parallel Identification Game (Improved Version)



Sample DC Circuit Problem and Solution



Special Pedagogical Features

- Can color code nodes to help identify them
- Can color series & parallel sets red to highlight them
- Can color code currents leaving a node or supernode and voltage drops around a loop
- Structured equation entry interface (shown at upper right) helps guide student learning

Summary

- We have expanded the usage of our software tutorials for the teaching of linear circuits classes to a total of 1020 students in 18 class sections at Arizona State University, University of Notre Dame, and two community colleges
- This expansion has been supported by developing an instructor web site to register students and monitor their progress in detail
- Student satisfaction has been high, with over 97% of students rating the tutorials as "very useful" or "somewhat useful" for learning the topics (74% said "very useful)
- Results have been consistent at two very different institutions, suggesting that the materials should be broadly applicable
- A controlled, randomized laboratory-based trial showed approximately 10X learning gains and higher satisfaction levels for the software when compared to conventional textbook-based exercises
- Analysis of ~193,000 log entries showed that providing detailed explanation is important in the case of wrong answers and when showing correct answers to students

Acknowledgments

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For Further Information or to Participate in this Project

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