Step-Based Tutoring System for Introductory Linear Circuit Analysis

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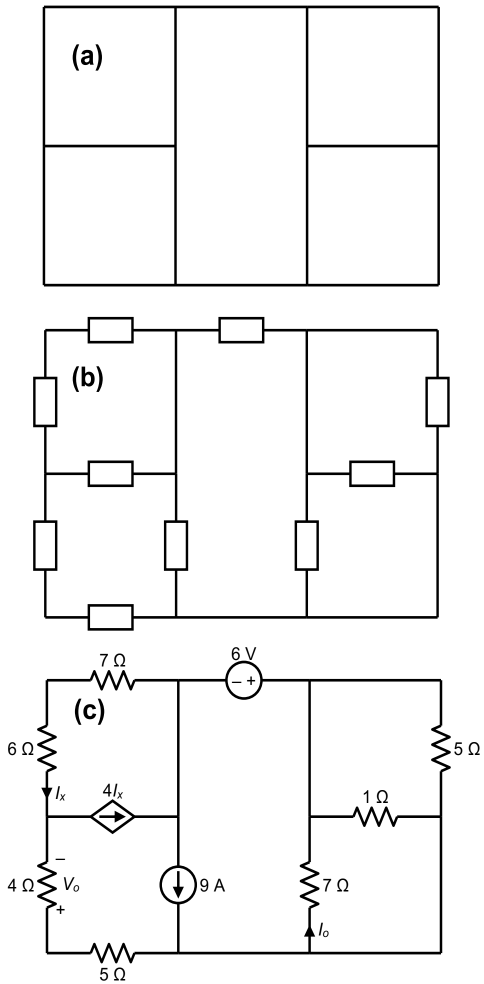
Introduction

- Linear circuit analysis is a key gateway course for electrical engineers and is taken by many other engineering majors
- To improve the student success rate, we are developing a computer-aided instructional tool as a substitute for conventional homework, using a step-based tutorial approach (considered more effective than answer-based tutors)
- Goals:
  - Provide immediate, detailed feedback on every step of a student's work
  - Provide an unlimited supply of fully worked and explained examples that are exactly isomorphic to the exercises students must complete
  - Enhance learning & reduce frustration
  - Promote complete mastery of concepts
  - Minimize manual grading

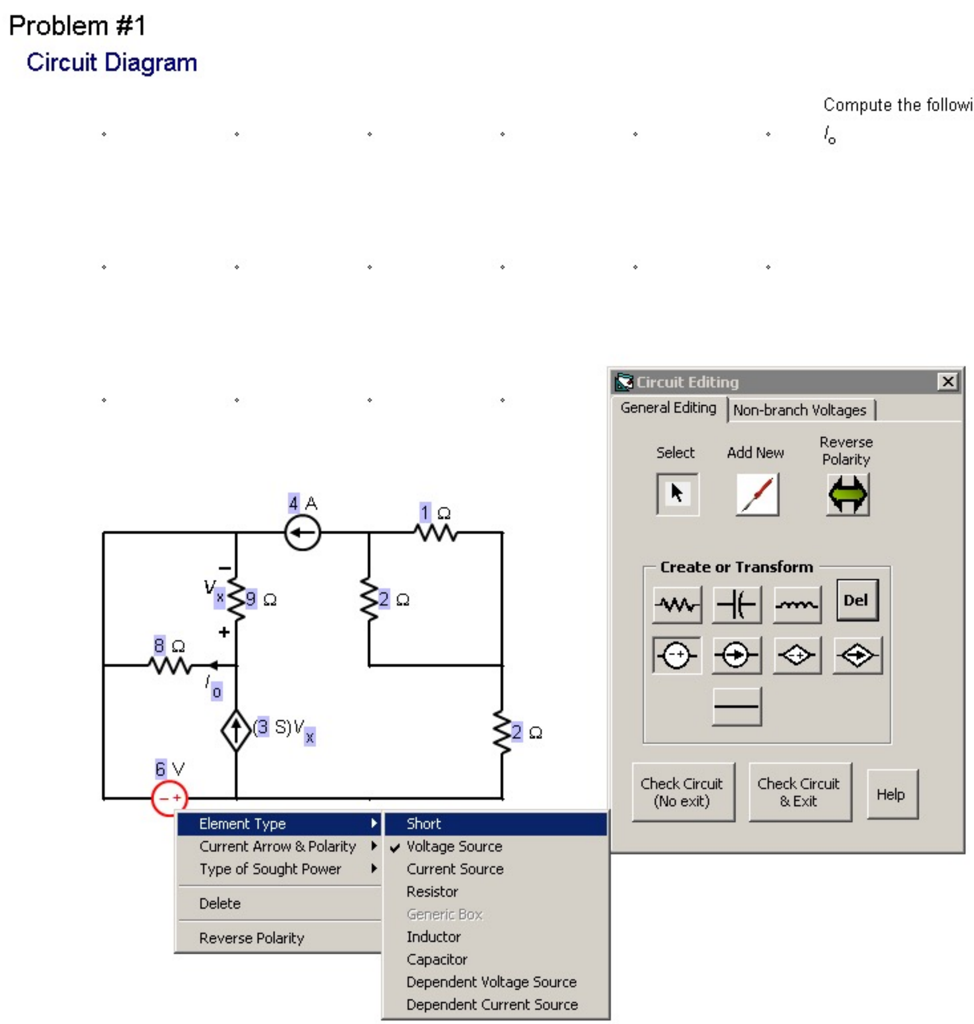
Random Circuit Generation Approach

- Can randomly generate netlists, then layouts based on them; or randomly generate a layout and extract the netlist (we use latter approach)
- We draw all circuits on square grids of specified sizes to facilitate the graphics (can represent *any* planar circuit)
- Cannot just "throw" random elements onto grid and discard undesirable circuits (combinatorial explosion)
- We use a three-step approach to avoid this problem:
  - Step (a): Generate a "topology" consisting only of opens and shorts; must have correct number of meshes, be connected and not hinged
  - Step (b): Replace some of the shorts by generic circuits elements, placing at least two/mesh (including outer mesh) to avoid shorted elements; check that result is not hinged
  - Step (c): Find all or many trees of this network, and place required number of voltage sources and inductors on the twigs, and required # of current sources & capacitors on the links (resistors can be placed anywhere). Then choose random element values and pick control variables for dependent sources (following additional rules for latter)
  - Step (d): Choose "sought variables" students are to find (currents, voltages, powers), following certain rules

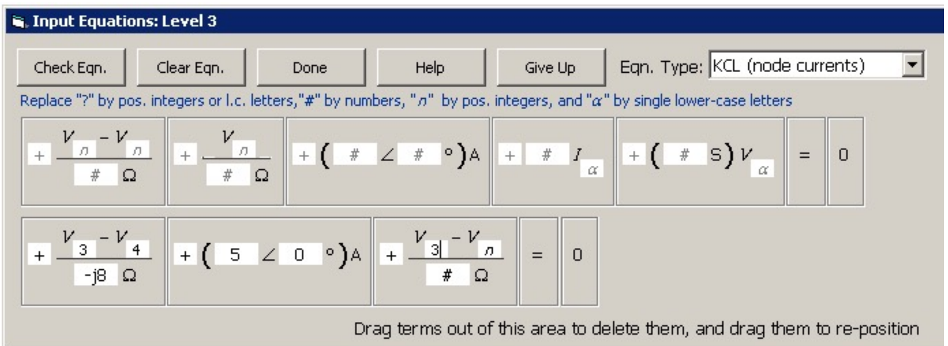
Three-step Process for Circuit Generation

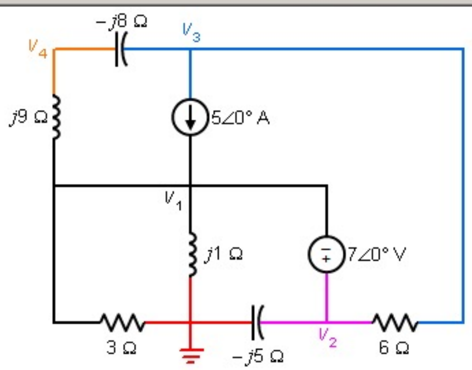


Interactive Circuit Editor Interface



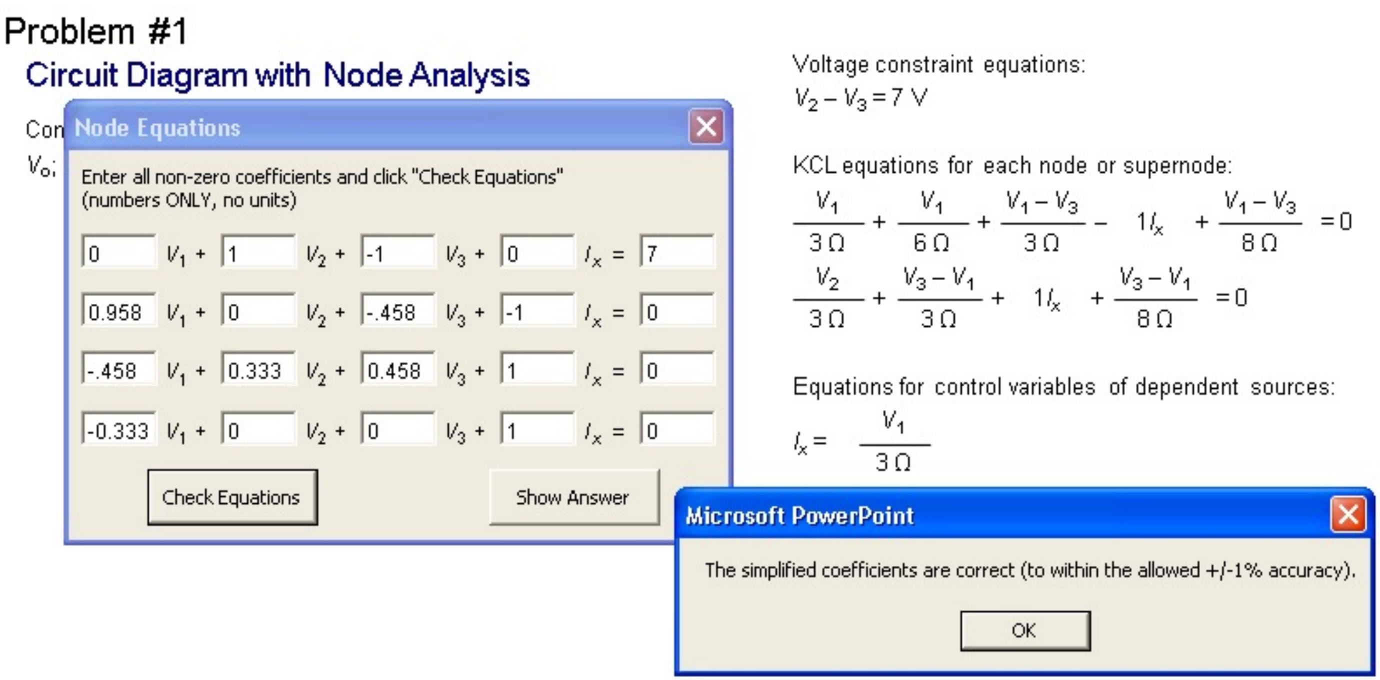
Equation Entry Interface (used in Equation Games)





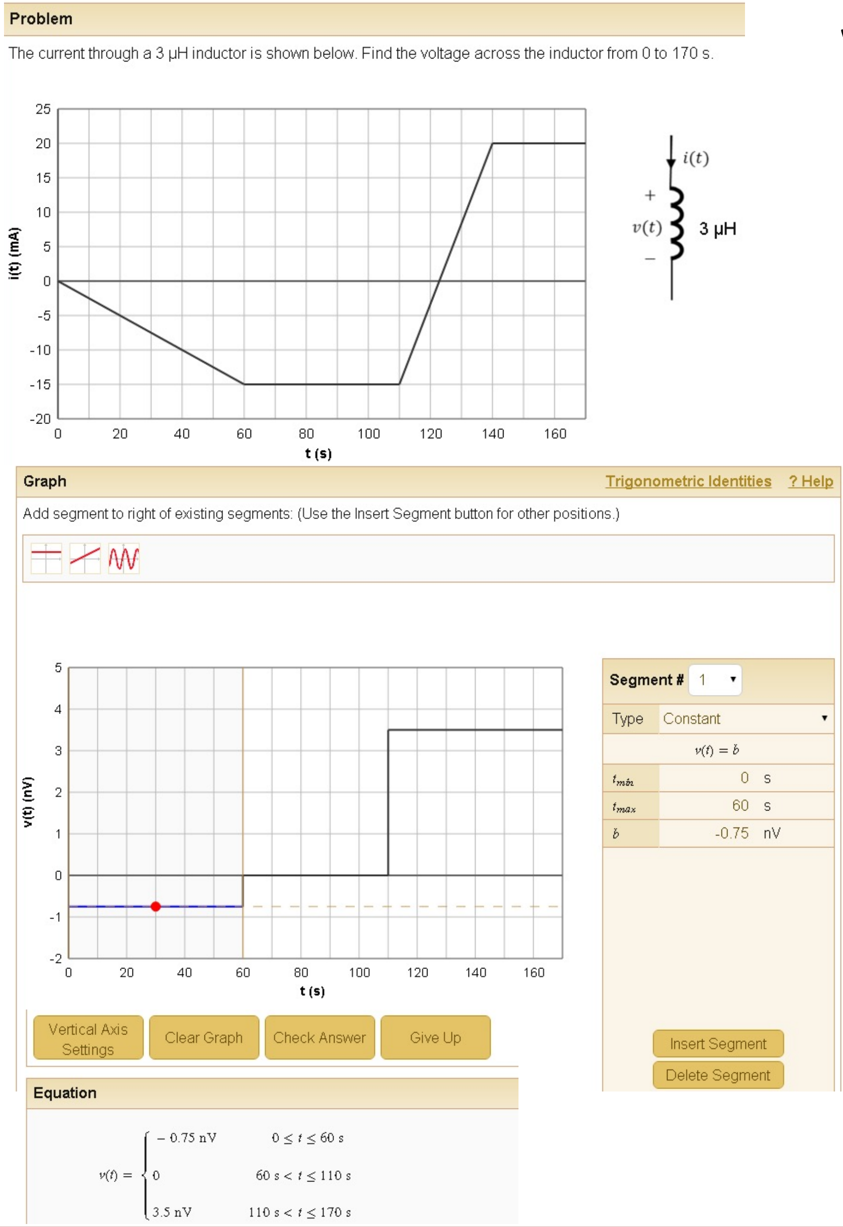
- Uses special templates to guide students as to proper form of various terms
- Students interactively drag the appropriate templates into the equation building area, then fill in the blanks to complete them
- Program automatically checks correctness of entries
- On “giving up,” the program shows the correct answers and explains them, then provides another problem of the same type & difficulty

Simplified Equation Entry Interface



- Used after entering original equations, to put in standard form

Arizona State University



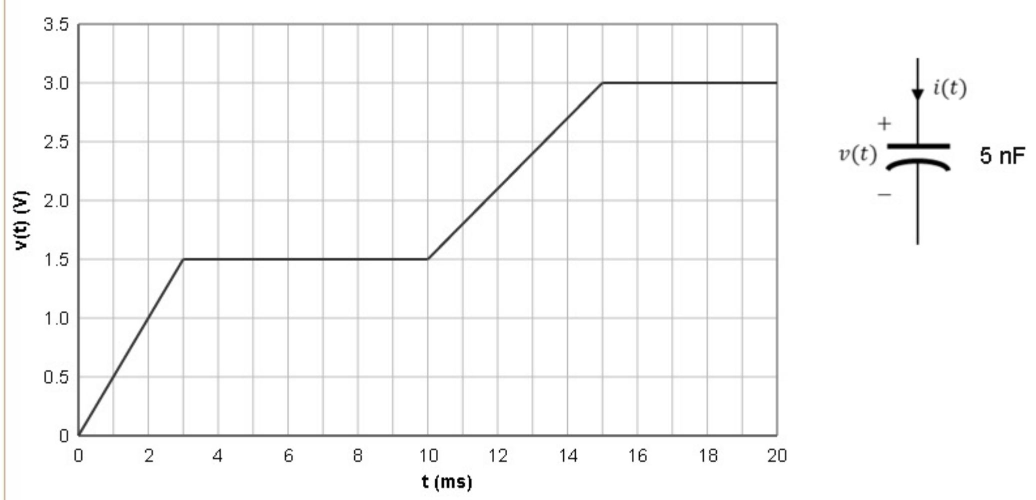
Waveform Sketching Interface

- Web-based application (no plug-ins required)
- Randomly generates piecewise waveforms such as current through an inductor, then asks student to plot other related quantities (such as the voltage or power)
- Students can select different functions such as constants, ramps, parabolas, exponentials, sinusoids, damped exponentials as needed for each segment of the graph, and adjust their parameters using handles or by typing
- Corresponding equations are then automatically generated and displayed
- Correctness of answers will be checked automatically

Example Waveform Sketching Solution (Capacitors & Inductors)

Problem

The voltage across a 5 nF capacitor is shown below. Find the current through the capacitor from 0 to 20 ms.



Solution:

First write an expression for the above graph:

Derivation of Expression for $v(t)$

In regions where the voltage is constant, the equations are trivial. In regions where the voltage is a ramp as a function of time, we use the two-point formula for the corresponding line:

$$v(t) = v_0 + \frac{(v_1 - v_0)}{(t_{max} - t_{min})}(t - t_{min}) = v_0 + m(t - t_{min}),$$

where v_0 is the voltage at time t_{min} and v_1 is the voltage at time t_{max}, and the slope m is computed as

$$m = \frac{(v_1 - v_0)}{(t_{max} - t_{min})}.$$

Example Waveform Sketching Solution (cont.)

- The voltage is a ramp from 0 to 3 ms with a slope

$$m = \frac{\Delta v}{\Delta t} = \frac{1.5\ \text{V} - 0}{3\ \text{ms} - 0} = 0.5\ \text{V/ms} = (0.5\ \text{V})/(10^{-3}\ \text{s}) = 0.5 \times 10^3\ \text{V/s} = 0.5\ \text{kV/s}.$$

Given that the voltage at t = 0 ms is 0 V,

$$v(t) = (0.5\ \text{kV/s})t \quad 0 \le t \le 3\ \text{ms}.$$

- The voltage is constant from 3 ms to 10 ms, so

$$v(t) = 1.5\ \text{V} \quad 3\ \text{ms} < t \le 10\ \text{ms}.$$

- The voltage is a ramp from 10 ms to 15 ms with a slope

$$m = \frac{\Delta v}{\Delta t} = \frac{3\ \text{V} - 1.5\ \text{V}}{15\ \text{ms} - 10\ \text{ms}} = 0.3\ \text{V/ms} = (0.3\ \text{V})/(10^{-3}\ \text{s}) = 0.3 \times 10^3\ \text{V/s} = 0.3\ \text{kV/s}.$$

Given that the voltage at t = 10 ms is 1.5 V,

$$v(t) = 1.5\ \text{V} + (0.3\ \text{kV/s})\,(t - 10\ \text{ms}) \quad 10\ \text{ms} < t \le 15\ \text{ms}.$$

- The voltage is constant from 15 ms to 20 ms, so

$$v(t) = 3\ \text{V} \quad 15\ \text{ms} < t \le 20\ \text{ms}.$$

In summary,

$$v(t) = \begin{cases} (0.5\ \text{kV/s})t & 0 \le t \le 3\ \text{ms} \\ 1.5\ \text{V} & 3\ \text{ms} < t \le 10\ \text{ms} \\ 1.5\ \text{V} + (0.3\ \text{kV/s})\,(t - 10\ \text{ms}) & 10\ \text{ms} < t \le 15\ \text{ms} \\ 3\ \text{V} & 15\ \text{ms} < t \le 20\ \text{ms} \end{cases}$$

The current through a capacitor is:

$$i(t) = C\frac{dv(t)}{dt}.$$

Using this equation, we take the derivative of the voltage expression to obtain our solution:

Details of Derivation

For $0 \le t \le 3\ \text{ms}$,

$$i(t) = C\frac{dv(t)}{dt} = (5\ \text{nF})\frac{d}{dt}\left[(0.5\ \text{kV/s})t\right]$$
$$= (5\ \text{nF})\,(0.5\ \text{kV/s}) = \left(5 \times 10^{-9}\ \text{F}\right)\left(0.5 \times 10^3\ \text{V/s}\right) = 2.5 \times 10^{-6}\ \text{C/s} = 2.5\ \mu\text{A},$$

because C = F V and A = C/s.

For $3\ \text{ms} < t \le 10\ \text{ms}$,

$$i(t) = C\frac{dv(t)}{dt} = (5\ \text{nF})\frac{d}{dt}(1.5\ \text{V}) = 0.$$

For $10\ \text{ms} < t \le 15\ \text{ms}$,

$$i(t) = C\frac{dv(t)}{dt} = (5\ \text{nF})\frac{d}{dt}\left[1.5\ \text{V} + (0.3\ \text{kV/s})\,(t - 10\ \text{ms})\right]$$
$$= (5\ \text{nF})\,(0.3\ \text{kV/s}) = \left(5 \times 10^{-9}\ \text{F}\right)\left(0.3 \times 10^3\ \text{V/s}\right) = 1.5 \times 10^{-6}\ \text{C/s} = 1.5\ \mu\text{A}.$$

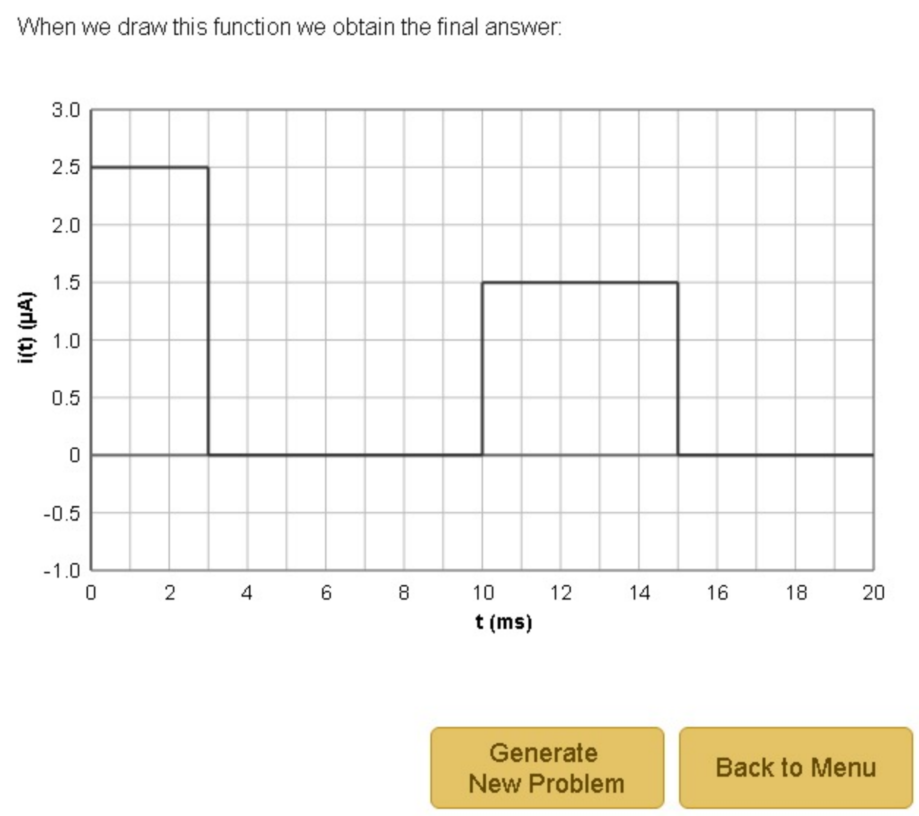
For $15\ \text{ms} < t \le 20\ \text{ms}$,

$$i(t) = C\frac{dv(t)}{dt} = (5\ \text{nF})\frac{d}{dt}(3\ \text{V}) = 0.$$

In summary,

$$i(t) = \begin{cases} 2.5\ \mu\text{A} & 0 \le t \le 3\ \text{ms} \\ 0 & 3\ \text{ms} < t \le 10\ \text{ms} \\ 1.5\ \mu\text{A} & 10\ \text{ms} < t \le 15\ \text{ms} \\ 0 & 15\ \text{ms} < t \le 20\ \text{ms} \end{cases}$$

Example Waveform Sketching Solution (cont.)



Laplace Transforms: Generation of Partial Fraction Inverse Transform Solutions (Real & Complex Poles) (Web-Based)

The goal is to find the inverse Laplace transform of the function,

$$\mathbf{F}(\mathbf{s}) = \frac{5(\mathbf{s}+40)}{(\mathbf{s}+10)(\mathbf{s}^2+10\mathbf{s}+29)}.$$

The first step is to factor the quadratic terms in $\mathbf{F}(\mathbf{s})$. For the general quadratic equation $a\mathbf{s}^2 + b\mathbf{s} + c = 0$, the roots are given by:

$$\mathbf{s}_{1,2} = \frac{-b}{2a} \pm \sqrt{\left(\frac{b}{2a}\right)^2 - \frac{c}{a}},$$

which implies

$$(\mathbf{s}-\mathbf{s}_1)(\mathbf{s}-\mathbf{s}_2) = 0.$$

For $\mathbf{s}^2 + 10\mathbf{s} + 29 = 0$, we have

$$\begin{aligned}\mathbf{s}_{1,2} &= \frac{-(10)}{2} \pm \sqrt{\left(\frac{10}{2}\right)^2 - 29} \\ &= -5 \pm j2.\end{aligned}$$

So,

$$\mathbf{s}^2 + 10\mathbf{s} + 29 = (\mathbf{s}+5-j2)(\mathbf{s}+5+j2).$$

Therefore, $\mathbf{F}(\mathbf{s})$ can be written in factored form as

$$\mathbf{F}(\mathbf{s}) = \frac{5(\mathbf{s}+40)}{(\mathbf{s}+10)(\mathbf{s}+5-j2)(\mathbf{s}+5+j2)}.$$

Laplace Transforms: Generation of Partial Fraction Inverse Transform Solutions (Real & Complex Poles) (cont.)

The inverse Laplace transform is obtained by expressing $\mathbf{F(s)}$ in a partial fraction expansion:

$$\mathbf{F(s)} = \frac{k_0}{\mathbf{s} + p_0} + \frac{\mathbf{k}_1}{\mathbf{s} + \mathbf{p}_1} + \frac{\mathbf{k}_1^*}{\mathbf{s} + \mathbf{p}_1^*},$$

where $p_0 = 10$, $\mathbf{p}_1 = 5 - j2$, and $\mathbf{p}_1^* = 5 + j2$.
Note: * denotes the complex conjugate of a complex number and $-p_0, -p_1$, etc. are the poles of $\mathbf{F(s)}$.

The values of $\mathbf{k}_i$'s are obtained as follows:

$$\mathbf{k}_i = (\mathbf{s} + p_i)\mathbf{F(s)}\Big|_{\mathbf{s} = -p_i}.$$

Therefore,

$$k_0 = \cancel{(\mathbf{s}+10)} \frac{5(\mathbf{s}+40)}{\cancel{(\mathbf{s}+10)}\,(\mathbf{s}+5-j2)(\mathbf{s}+5+j2)}\Bigg|_{\mathbf{s}=-10}$$

$$= \frac{5(-10+40)}{(-10+5-j2)(-10+5+j2)}$$

$$= \frac{5(30)}{(-5-j2)(-5+j2)}$$

$$= 5.1723$$

Laplace Transforms: Generation of Partial Fraction Inverse Transform Solutions (Real & Complex Poles) (cont.)

$$\mathbf{k}_1 = \cancel{(\mathbf{s}+5-j2)}\left.\frac{5(\mathbf{s}+40)}{(\mathbf{s}+10)\,\cancel{(\mathbf{s}+5-j2)}\,(\mathbf{s}+5+j2)}\right|_{\mathbf{s}=-(5-j2)}$$

$$= \frac{5(-5+j2+40)}{(-5+j2+10)(-5+j2+5+j2)}$$

$$= \frac{5(35+j2)}{(5+j2)(j4)}$$

$$= 8.1374\angle -108.53^\circ$$

(The numerical evaluations above should be carried out in one step on a calculator, using complex number capabilities when required.)

Expressing $\mathbf{F}(\mathbf{s})$ as a partial fraction expansion,

$$\mathbf{F}(\mathbf{s}) = \frac{5.1723}{\mathbf{s}+10} + \frac{8.1374\angle -108.53^\circ}{\mathbf{s}+5-j2} + \frac{8.1374\angle 108.53^\circ}{\mathbf{s}+5+j2}.$$

Laplace Transforms: Generation of Partial Fraction Inverse Transform Solutions (Real & Complex Poles) (cont.)

From the Laplace transform table, we have

$$\mathcal{L}^{-1}\left[\frac{k}{\mathbf{s}+a}\right] = k\,e^{-at}\,u(t)$$

$$\mathcal{L}^{-1}\left[\frac{|\mathbf{k}|\angle\theta}{\mathbf{s}+\alpha-j\beta} + \frac{|\mathbf{k}|\angle-\theta}{\mathbf{s}+\alpha+j\beta}\right] = 2\,|\mathbf{k}|\,e^{-\alpha t}\cos(\beta t+\theta)\,u(t).$$

Thus, the inverse Laplace transform(s) of the term(s) in $\mathbf{F}(\mathbf{s})$ are

$$\mathcal{L}^{-1}\left[\frac{5.1723}{\mathbf{s}+10}\right] = 5.1723\,e^{-10t}\,u(t),$$

where $k = 5.1723$ and $a = 10$;

$$\mathcal{L}^{-1}\left[\frac{8.1374\angle-108.53^\circ}{\mathbf{s}+5-j2} + \frac{8.1374\angle 108.53^\circ}{\mathbf{s}+5+j2}\right] = 16.2748\,e^{-5t}\cos(2t-108.53^\circ)\,u(t),$$

where $|\mathbf{k}| = 8.1374$, $\theta = -108.53^\circ$, $\alpha = 5$, and $\beta = 2$.

Therefore, the final answer is

$$\boxed{f(t) = \left[5.1723\,e^{-10t} + 16.2748\,e^{-5t}\cos(2t-108.53^\circ)\right]u(t).}$$

Currently Released Tutorials (17)

Grades

When a game is completed it will be shown in green. If it is not green, it has not been marked as completed.

Click on a game's title in the first column to start it.

Basic Electrical Waveforms	Not started	
Series/Parallel	0 / 4 levels completed	Next step: Tutorial
Series/Parallel with Terminals	0 / 2 levels completed	Next step: Pre-Test
Resistor Simplification	0 / 3 levels completed	Next step: Tutorial
DC Node Equations	Not started	
DC Node Solutions	0 / 4 levels completed	Next step: Level 1
DC Mesh Equations	Not started	
DC Mesh Solutions	Not started	
Capacitors and Inductors	Not started	
L/C Simplification	0 / 3 levels completed	Next step: Level 1
Impedance Simplification	Not started	
AC Nodal Equations	Not started	
AC Node Solutions	Not started	
AC Mesh Equations	Not started	
AC Mesh Solutions	Not started	
Laplace Transform	Completed	
Inverse Laplace Transform	Completed	

Evaluation Results: Controlled Laboratory-Based Study

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.

Cohen *d*-value: 1.21 σ; statistically significant ($p < 0.05$)

- Covered series-parallel identification and node analysis
- Paid volunteers (were taking or had taken course in last year) randomly assigned to use tutorials or work textbook problems
- Two similar tests randomly assigned as either pre-tests or post-tests to measure learning

TABLE II. RESULTS OF INSTRUCTIONAL MATERIALS MOTIVATION SURVEY (SCALE = 1-5, 5=BEST)

Group	Statistic	Total	Attention	Relevance	Confidence	Satisfaction
Software Users	Means	3.54	3.44	3.22	3.94	3.62
	Std. Dev.	0.40	0.49	0.60	0.52	0.66
	Medians	3.57	3.54	3.11	3.83	3.75
Textbook Users	Means	3.01	2.84	2.99	3.51	2.65
	Std. Dev.	0.77	0.80	0.83	0.99	0.91
	Medians	3.01	2.88	3.00	3.72	2.33
Comparisons	Diff. of Means	0.53*	0.60*	0.23	0.44	0.97*
	Pooled Std. Dev.	0.58	0.64	0.70	0.75	0.76
	Cohen *d*-value	0.91*	0.94*	0.33	0.58	1.27*

*Statistically significant difference with $p < 0.05$.

Evaluation Results: Controlled Classroom-Based Study (F'14)

- Compared Circuit Tutor to widely-used, commercial, publisher-based homework "System X"
- ~70 students randomly assigned to do homework using:

  A) Circuit Tutor for node analysis, and System X for mesh analysis

  (similar problems selected to those in Circuit Tutor, with usual right/wrong feedback & four attempts)

or B) System X for node analysis, and Circuit Tutor for mesh analysis

- After completing the assigned work for credit, students were given the OPTION (for <u>no</u> additional credit) to use the system they were not originally assigned to use on each topic

Comparison Item	Circuit Tutor	System X
Ave. homework assignment scores (σ)*	40.2/50 (16.2)	33.6/50 (15.9)
Received full credit on assignment (100%)	64%	26%
Did ≥ 1 level or problem voluntarily (no credit)	33%/32%**	0%/0%**
Did ≥ 8/10 levels or problems voluntarily***	15%/16%**	0%/0%**
Ave. # of levels or problems completed voluntarily	6.5/10	0
# of unsolicited comments favoring the system	7	0

*Combination of node and mesh exercises, equal weights
Effect size of Cohen $d = 0.41\ \sigma$, statistically significant with $p < 0.008$

** Group A/Group B ***Misstated in manuscript as 10/10

Evaluation Results: Controlled Classroom-Based Study (F'15)

- Essentially repeated the A/B study of Fall 2014, comparing Circuit Tutor to publisher-based System X for node & mesh analysis; again involved ~70 students
- This time, a post-test (in-class quiz) was used to compare actual student learning for each group, and students were specifically surveyed on which system they preferred, and why

Comparison Item	Circuit Tutor	System X
Ave. post-test score on node analysis*	72%	49%
Ave. post-test score on mesh analysis**	71%	65%
Students who preferred each system	86%	9%
Students who feel the system taught them more effectively than the other one	94%	3%

*Effect size of Cohen $d = 0.72\ \sigma$, statistically significant with $p < 0.05$
**Difference not statistically significant ($p = 0.38$)

Usage & Survey Statistics

- To date, system has been used by over 2300 students in 54 class sections at eight different colleges and universities
- Diverse set of institutions have used system:
  Arizona State University, University of Notre Dame, University of the Pacific, Morgan State University, Messiah College, Auburn University, South Mountain Community College, and Chandler-Gilbert Community College
- Short survey at end of each tutorial: How useful was the system to learn the material?
  Very useful: 70%
  Somewhat useful: 25%
  Not very useful: 2%
  Waste of Time: 2%
  I.e., 96% favorable
- More detailed 12-question survey at end of semester in three categories: (4-point Likert scale)

Useful and well-designed?	87% favorable
Difficulty and coverage appropriate?	85% favorable
Preferred over conventional homework assignments?	78% favorable

Student Comments

Good job on the game! It was actually fun going through it and trying to do a good job! Thanks for making this.

Worked as intended, didn't take too long, kind of fun, and I feel like it helped!

I HAVEN'T EVEN LEARNED IT YET BUT IT WAS REALLY EASY TO GRASP USING THIS! YAY

I really thought it was awesome; it was very helpful. I understood the concepts, but this helped me develop a thought process on it.

I like how you are not marked off for getting on wrong, you just get to try again. You only really fail if you give up, and that is reassuring.

These modules honestly do help me learn circuit analysis. I feel that it is extremely helpful to have a good amount of practice problems, and a system that provides instant feedback. This helps me learn the correct techniques and master

I AM A PRO AT THIS. Major self-confidence booster. Really though, I feel like I'm talented at this node analysis!

It definitely helped me understand supernodes, I think this was more usefull than book work

This exercise helped me understand loop analysis very well. The assignment was great.

I would prefer to have a statistics page showing # of correct and incorrect attempts and possibly even a ladder [leader?] board showing how well different students did as opposed to everyone getting a congratulatory gold medal for doing thier hw

Wow is all i can say... This is the best, better than any hw I have done so far

Conclusions

- We are developing a step-based tutoring system with (currently) 17 tutorials to teach linear circuit analysis with several novel features:
  - Accepts and checks many forms of student input using special interfaces, such as re-drawn circuit diagrams, equations, simplified & matrix equations, waveform sketches, Bode plots, and numerical and multiple-choice answers
  - Randomly generates circuit problems of varying topologies as well as element values, providing an unlimited source of fully worked and explained examples and exercises that are isomorphic to the examples; has special pedagogical features
- Program has been extensively used by >2300 students in 8 institutions
- Significant learning gains of $d = 1.21\sigma$ compared to paper homework and 0.72σ for node analysis compared to commercial, publisher-based system; higher homework scores (0.41σ) and strongly preferred by students over publisher-based system and paper homework

Comparison to Previous Work

- We provide an unlimited supply of topologically different circuit diagrams, generated on demand. Commercial publisher-based systems typically vary only the element values, making different versions of a problem essentially the same. Other systems have used limited, pre-defined problem banks. In our system, every student gets completely different, error-free problems!
- Unlike other systems, if a student gives up on a problem or fails to solve it correctly in a certain number of attempts, we provide a fully explained solution, and then present another problem of the same type (as many times as needed!)
- We generate full (error-free) solutions to problems using the methods typically used in textbooks (voltage/current division, node analysis, superposition, etc.) rather than the numerical approaches used in software like PSPICE
- We accept a wide variety of student inputs such as interactively redrawn circuit diagrams, equations (using a template-based interface), simplified equations, matrix equations, interactively sketched waveforms, Bode plots, numerical answers, and traditional multiple choice or short answers. Most existing systems are limited to numerical answers and short answers, providing no feedback on intermediate steps

Comparison to Previous Work (cont.)

- We use special pedagogical devices, such as color coding of nodes (very popular with students!), color coding of currents or voltage drops and the corresponding terms in KCL or KVL equations, etc. No other software implements these methods
- An unlimited supply of fully worked and explained examples is always provided that are exactly isomorphic to the exercises, which is known to be important to learning, particularly in the early stages (see, e.g., J. Sweller, J. J. G. Van Merrienboer, and F. Paas, "Cognitive architecture and instructional design," Educ. Psychol. Rev., vol. 10, pp. 251-296, 1998)
- We aim to cover the full content of a typical linear circuits course, whereas many other systems have been more limited in scope
- Very importantly, we are conducting rigorous, controlled, randomized evaluations of our software both in laboratory and classroom-based settings, as well as collecting quantitative and qualitative survey data from students, unlike many previous studies

Problem #1

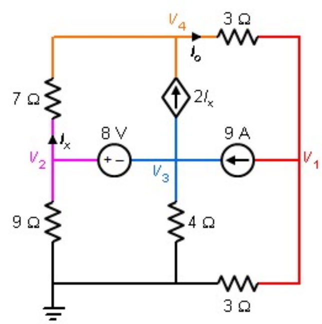
Circuit Diagram with Node Analysis

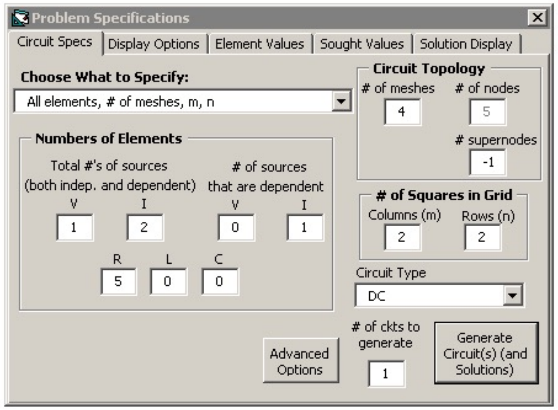
Compute the following quantity for this circuit:

I_o

Example DC Circuit & Solution

Note color coding of nodes; pedagogical feature





Voltage constraint equations:

$V_2 - V_3 = 8\text{ V}$

KCL equations for each node or supernode:

$$\frac{V_1}{3\,\Omega} + 9\text{ A} + \frac{V_1 - V_4}{3\,\Omega} = 0$$

$$\frac{V_2}{9\,\Omega} + \frac{V_3}{4\,\Omega} + \frac{V_2 - V_4}{7\,\Omega} + 2I_x - 9\text{ A} = 0$$

$$\frac{V_4 - V_2}{7\,\Omega} - 2I_x + \frac{V_4 - V_1}{3\,\Omega} = 0$$

Equations for control variables of dependent sources:

$$I_x = \frac{V_2 - V_4}{7\,\Omega}$$

Simplified node equations:

$$\begin{array}{rrrrrcl}
0V_1 & +V_2 & -V_3 & +0V_4 & +0I_x & = & 8 \\
0.667V_1 & +0V_2 & +0V_3 & -0.333V_4 & +0I_x & = & -9 \\
0V_1 & +0.254V_2 & +0.25V_3 & -0.143V_4 & +2I_x & = & 9 \\
-0.333V_1 & -0.143V_2 & +0V_3 & +0.476V_4 & -2I_x & = & 0 \\
0V_1 & -0.143V_2 & +0V_3 & +0.143V_4 & +I_x & = & 0
\end{array}$$

Matrix form of node equations:

$$\begin{array}{c}
\begin{array}{ccccc} V_1 & V_2 & V_3 & V_4 & I_x \end{array} \\
\begin{bmatrix}
0 & 1 & -1 & 0 & 0 \\
0.667 & 0 & 0 & -0.333 & 0 \\
0 & 0.254 & 0.25 & -0.143 & 2 \\
-0.333 & -0.143 & 0 & 0.476 & -2 \\
0 & -0.143 & 0 & 0.143 & 1
\end{bmatrix}
\end{array}
\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ I_x \end{bmatrix} = \begin{bmatrix} 8 \\ -9 \\ 9 \\ 0 \\ 0 \end{bmatrix}$$

Sought variable equations:

$$I_o = \frac{V_4 - V_1}{3\,\Omega}$$

Solution:

$V_1 = -11.5\text{ V}$; $V_2 = 16.1\text{ V}$; $V_3 = 8.13\text{ V}$; $V_4 = 4.05\text{ V}$; $I_x = 1.73\text{ A}$

$I_o = 5.18\text{ A}$

ARIZONA STATE UNIVERSITY

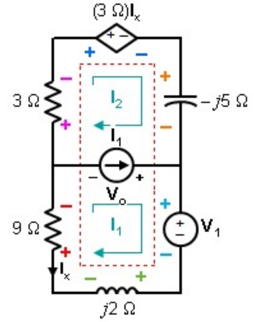
Example AC Circuit (Phasor Analysis)

ay Equations: Level 4

Explain Constraint Equations | Explain This KVL Equation | Here are the correct equations. | Next

Compute the following quantity for this circuit:

$\mathbf{V}_o$



$\mathbf{V}_1(j\omega) = 2\angle 0°$ V

$\mathbf{I}_1(j\omega) = 3\angle 0°$ A

Each colored +/– symbol pair corresponds to a term in KVL equation #1 of 1.

Current constraint equations:

$\mathbf{I}_1 - \mathbf{I}_2 = 3\angle 0°$ A

KVL equations for each mesh or supermesh:

$\mathbf{I}_1(9\ \Omega) + \mathbf{I}_2(3\ \Omega) + (3\ \Omega)\mathbf{I}_x + \mathbf{I}_2(-j5\ \Omega) + 2\angle 0°\ \mathrm{V} + \mathbf{I}_1(j2\ \Omega) = \mathbf{0}$

Equations for control variables of dependent sources:

$\mathbf{I}_x = -\mathbf{I}_1$

Simplified mesh equations:

$$\begin{aligned} 1\,\mathbf{I}_1 \quad & -1\,\mathbf{I}_2 & +0\,\mathbf{I}_x &= 3\angle 0° \\ (9+j2)\,\mathbf{I}_1 \quad & +(3-j5)\,\mathbf{I}_2 & +3\,\mathbf{I}_x &= 2\angle 180° \\ 1\,\mathbf{I}_1 \quad & +0\,\mathbf{I}_2 & +1\,\mathbf{I}_x &= 0 \end{aligned}$$

Matrix form of mesh equations:

$$\begin{bmatrix} 1 & -1 & 0 \\ 9+j2 & 3-j5 & 3 \\ 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} \mathbf{I}_1 \\ \mathbf{I}_2 \\ \mathbf{I}_x \end{bmatrix} = \begin{bmatrix} 3\angle 0° \\ 2\angle 180° \\ 0 \end{bmatrix}$$

Sought variable equations:

Finding the voltage $\mathbf{V}_o$ across the $\mathbf{I}_1$ current source is tricky, because the voltage across a current source is whatever it needs to be. Therefore, we need to sum all voltage drops from one end of this source to the other using a path that does NOT go through the current source, and use KVL.

The drops are considered positive if they have the same polarity as the desired voltage, or negative if they are reversed.

We choose to do this on the side where the resulting expression will be the simplest, using mesh # 1.

$\mathbf{V}_o = \mathbf{I}_1(9\ \Omega) + 2\angle 0°\ \mathrm{V} + \mathbf{I}_1(j2\ \Omega)$

Solution:

$\mathbf{V}_o = 17.78\angle{-30.41}°$ V

$\mathbf{I}_1 = 1.745\angle{-46.55}°$ A; $\mathbf{I}_2 = 2.201\angle{-144.9}°$ A; $\mathbf{I}_x = 1.745\angle 133.5°$ A

Matrix Equation Entry Interface

Problem #1

Circuit Diagram with Node Analysis

Compute the following quantity for this circuit:

V_o

Voltage constraint equations:

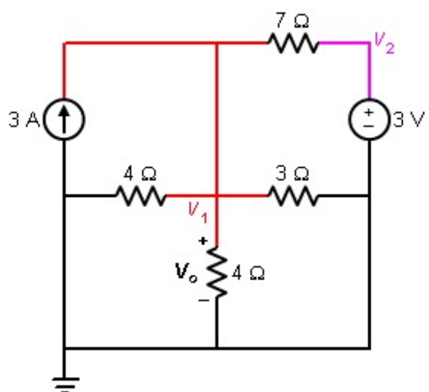
$V_2 = 3\text{ V}$

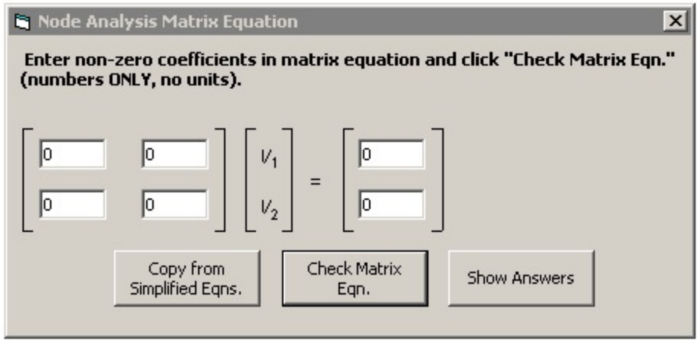
KCL equations for each node or supernode:

$$\frac{V_1}{4\,\Omega} - 3\text{ A} + \frac{V_1}{4\,\Omega} + \frac{V_1}{3\,\Omega} + \frac{V_1 - V_2}{7\,\Omega} = 0$$

Simplified node equations:

$$\begin{aligned} 0V_1 \quad &+ V_2 &= 3 \\ 0.976V_1 \quad &- 0.143V_2 &= 3 \end{aligned}$$





- Used to put simplified equations into matrix form prior to solving

Instructor Web Site

Circuit Tutor

Administrator
Account
Logout

Home | Documentation | Logs | Server Info | View

Home > Courses > EEE 202: Circuits I > Students

Students

School: Arizona State University (Tempe campus)
Instructor: Meng Tao

Course: EEE 202: Circuits I
Term: 2015 Spring

Students Registered: 79 out of 81 (97.5%)

Export as CSV | New Student(s)

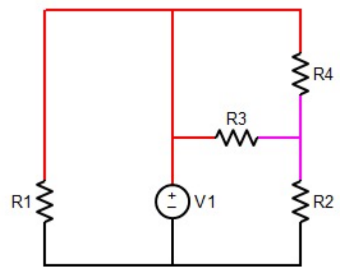
ID	Registered	User Code	Pre-Test	Post-Test	Ser/Par	Terminals	Combine R	DC Node Eq	DC Node Sol	DC Mesh Eq	DC Mesh Sol	Combine C & L	Combine Z	AC Node Eq	AC Node Sol	AC Mesh Eq	AC Mesh Sol	Survey	Actions
2824	Yes	STTN5M-KK66-HPPY	20 / 30	0 / 30	0 / 4	0 / 2	0 / 4	5 / 5	0 / 5	0 / 5	0 / 5	4 / 4	0 / 3	0 / 5	0 / 4	0 / 5	0 / 4	No	View Log
2832	Yes	STTN5M-KK66-J2PE	24 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	5 / 5	5 / 5	5 / 5	4 / 4	3 / 3	5 / 5	2 / 4	5 / 5	4 / 4	No	View Log
2799	Yes	STTN5M-KK66-J9MD	15 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	4 / 5	5 / 5	4 / 5	4 / 4	0 / 3	5 / 5	0 / 4	5 / 5	0 / 4	No	View Log
2817	Yes	STTN5M-KK66-JGK5	24 / 30	0 / 30	4 / 4	2 / 2	4 / 4	0 / 5	0 / 5	0 / 5	0 / 5	0 / 4	0 / 3	0 / 5	0 / 4	0 / 5	0 / 4	No	View Log
2823	Yes	STTN5M-KK66-JSNF	11 / 30	0 / 30	4 / 4	2 / 2	4 / 4	0 / 5	0 / 5	5 / 5	0 / 5	4 / 4	0 / 3	0 / 5	0 / 4	5 / 5	0 / 4	No	View Log
2860	Yes	STTN5M-KK66-L282	8 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	3 / 5	0 / 5	0 / 5	4 / 4	0 / 3	0 / 5	0 / 4	0 / 5	0 / 4	No	View Log
2850	Yes	STTN5M-KK66-LP9Y	11 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	5 / 5	5 / 5	5 / 5	4 / 4	3 / 3	5 / 5	4 / 4	5 / 5	4 / 4	No	View Log
2821	Yes	STTN5M-KK66-LPE7	11 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	5 / 5	5 / 5	5 / 5	4 / 4	3 / 3	5 / 5	4 / 4	5 / 5	4 / 4	No	View Log
2795	Yes	STTN5M-KK66-LR7G	26 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	5 / 5	5 / 5	5 / 5	4 / 4	3 / 3	5 / 5	4 / 4	5 / 5	4 / 4	No	View Log
2794	Yes	STTN5M-KK66-MUEA	12 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	4 / 5	0 / 5	0 / 5	0 / 4	0 / 3	0 / 5	0 / 4	0 / 5	0 / 4	No	View Log
2818	Yes	STTN5M-KK66-N6CA	28 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	5 / 5	5 / 5	5 / 5	4 / 4	3 / 3	5 / 5	3 / 4	5 / 5	4 / 4	No	View Log
2856	Yes	STTN5M-KK66-NYUK	9 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	5 / 5	5 / 5	5 / 5	4 / 4	3 / 3	5 / 5	4 / 4	5 / 5	4 / 4	No	View Log
2807	Yes	STTN5M-KK66-PFFR	7 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	5 / 5	5 / 5	5 / 5	4 / 4	3 / 3	5 / 5	2 / 4	5 / 5	2 / 4	No	View Log
2820	Yes	STTN5M-KK66-PNHB	11 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	5 / 5	5 / 5	5 / 5	4 / 4	3 / 3	5 / 5	0 / 4	5 / 5	2 / 4	No	View Log
2790	Yes	STTN5M-KK66-PS3G	9 / 30	0 / 30	4 / 4	2 / 2	4 / 4	5 / 5	3 / 5	5 / 5	5 / 5	4 / 4	3 / 3	5 / 5	4 / 4	5 / 5	4 / 4	No	View Log
		Completed	79	0	76	75	75	75	55	73	66	73	61	65	40	63	42	0	
		% Completed	98%	0%	94%	93%	93%	93%	68%	90%	81%	90%	75%	80%	49%	78%	52%	0%	

- Students identified only by codes to be FERPA-compliant (only instructor knows actual student identities)
- Can monitor progress in each tutorial, or bore down to detailed logs for each student

Web-Based Tutorial Engine

Series/Parallel Tutorial

Section 6 of 12



Now, let's study series connections. In this circuit, are R2 and R4 in series?

- Yes
- No

Submit

- Used to give tutorial instruction prior to exercises, using multiple choice and similar short-answer questions
- Authoring interface under development to facilitate easy writing of tutorials by developers and instructors
- Can allow branching depending on multiple student answers
- Questions stored in human-readable JSON format

Series-Parallel Identification Game