# Electricity and Electronics I

Last update 4 June 2024

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Essential information about this course:

- This course is a mix of theory and hands-on experiments. Each class session runs two hours long, approximately half of it focused on theory and the other half on application.

- *There will be no lecture during the theory portion of each class session.* At-home reading assignments and written summaries replace lecture, allowing us to spend our class time together discussing the text and solving problems. The basic expectation for each student is a good-faith effort every day to digest the material, and full engagement with classmates during class sessions as we challenge and support one another’s learning.

- You are expected to keep a journal of your learning. This is where you will write your summaries of the assigned reading. Any format is welcome so long as it may be easily shared with the entire class every day.

- *The experiments you will run are not pre-designed.* You will plan and execute each experiment, just like a real scientific experiment where the outcome is not necessarily known.

- You are not expected to master all concepts on your own. If and when you are confused, try to identify as precisely as you can the source of your confusion. This is extremely helpful to the instructor. Document all questions that come to mind, and raise those questions during class.

- Expect to make mistakes, and to have those mistakes gently and respectfully corrected. Be gracious with yourself and with others in this class as they make their own mistakes. *This is a learning community, and together we will de-stigmatize error.*

- You should budget a minimum of 20 hours per week for this course, approximately 10 hours in-class with discussions and experimentation, and approximately 10 hours out-of-class preparation in the form of reading and writing.

- This course document and all reading assignments are open-source and publicly available at the *Modular Electronics Learning Project* webpage ([https://ibiblio.org/kuphaldt/socratic/model](https://ibiblio.org/kuphaldt/socratic/model))
Required tools, supplies, components, and software

Tool List

- 18-24 gauge wire cutter/stripper pliers
  → *e.g.* 8-inch 4-way wire stripper from Harbor Freight, about $5
- Small needle-nose pliers
  → *e.g.* Pittsburgh 5-3/4-inch pliers from Harbor Freight, about $2
- Small diagonal (side) wire cutters
  → *e.g.* Pittsburgh 6-inch pliers from Harbor Freight, about $3
- Screwdrivers, slotted and phillips
- Inexpensive multimeter
  → *e.g.* 7-function digital multimeter from Harbor Freight, about $7
  → *e.g.* Gardner-Bender digital or analog multimeters from The Home Depot, about $18
- Digital oscilloscope
  → *e.g.* Siglent SDS1052DL+, about $300
- Set of jumper wires with alligator-clip ends
  → *e.g.* KAIWEETS 10-piece set from Amazon.com, about $5
- Set of banana-plug to alligator clip jumper wires
- Solderless breadboard
- Terminal blocks (at least ten terminals mounted on DIN rail)

Software List (all free downloads)

- Download – Python (will use Python interpreter shell as a powerful scientific calculator)
  → Alternatively, use [www.python.org/shell](http://www.python.org/shell) online interpreter
- Download – word processor or text editor for journal-writing (recommended text editors include VS Code or Notepad++)
- Download – Arduino development software
- Download – CLICK Programming software for Automation Direct PLCs
Supply List

- Spool of 22-gauge solid wire for use with breadboards and soldering
  → *e.g. TUOFENG 22 AWG hook up wire kit from Amazon.com, about $15*
- Spool of enameled “magnet” wire for creating electromagnets
- Small solar panel (25 Watts or less)
- Bar magnets
- Small magnetic compasses
- String or dental floss
- 120 VAC power cords

Passive components
- Assortment of 1/4 Watt resistors (1 k Ohm through 100 k Ohm)
- Low-value “shunt” resistors (between 1 Ohm and 10 Ohms)
- Pushbutton switches
- Ceramic capacitors (0.1 uF, 1 uF)
- Aluminum electrolytic capacitors (10 uF, 100 uF, 1000 uF)
- DC “hobby” permanent magnet motor
- AC shaded-pole induction motor (*e.g. bathroom ventilation fan motor*)
- CdS photocells
- Moving-coil speaker
- Control power transformer (step-down from 120 VAC to 12 VAC)
- “Ice-cube” style electromechanical relays
- 1N4001 rectifying diodes
- Bridge rectifier assemblies
- Low-voltage incandescent lamps
- Light-emitting diodes
- Neon lamp
- Cartridge-style fuses and fuseholders suitable for 120 VAC

Active components
- LM7805 voltage regulators
- LM339 or CA339 quad comparator ICs
- 555 timer ICs
- Power BJTs (*e.g. TIP31, TIP32*)
- Power MOSFETs (*e.g. IRF510*)
- CD4071 or 74HC32 quad 2-input OR gate ICs
- CD4001 or 74HC02 quad 2-input NOR gate ICs
- CD4081 or 74HC08 quad 2-input AND gate ICs
- CD4011 or 74HC00 quad 2-input NAND gates
- CD4070 quad 2-input XOR gate ICs
- CD4069 or 74HC04 hex inverter gate ICs
- CD4029 presettable up/down counter ICs

Programmable components
- Arduino Nano or equivalent microcontroller able to plug into a solderless breadboard
- Automation Direct “CLICK” programmable logic controller (PLC) with 120 VAC power supply, I/O capable of inputting and outputting discrete DC signals, and a USB-to-serial programming cable
What to write in your journal

Here are some specific suggestions of what to write in your journal when learning a technical subject:

✓ Maintain a glossary containing all the new terms you learn, new schematic symbols you encounter, commonly-used laws and principles, commonly-used mathematical formulae, and problem-solving strategies. Locate this glossary in some easy-to-reference place within your journal, for example at the very beginning.

✓ Try to explain what you have learned in the simplest possible terms, devoid of technical jargon, as though explaining it to someone lacking any prior knowledge of the subject. Analogies are helpful!

✓ Include helpful images, graphs, tables, and other visual aids.

✓ Describe what you find makes sense to you, as well as what does not.

✓ Document any epiphanies you experience as well as the apparent reason(s) for them.

✓ Record your mistakes and misconceptions when you identify them, as well as your successes.

✓ Include your attempts at solving homework and practice problems.

✓ Work through mathematical examples shown in the text to prove to yourself you understand them, and document this work in your journal as well.

✓ Include short code examples if your studies include computer programming of any kind.

✓ If copying verbatim from a source text, ALWAYS cite the source from which it came! Otherwise, everything in your journal should be your own original work.

✓ When referencing multiple sources, compare and contrast their approaches to the subject.

✓ Occasionally review what you’ve previously written in your journal, and reflect on your progress as revealed by those entries.
Instructor guidelines

The design and structure of this course is quite unconventional, but proven to deliver robust outcomes.

In addition to imparting technical knowledge and skill related to the subjects of electricity and electronics, this course seeks to also teach students how to think clearly and critically about these subjects. To this end, students first encounter new subject matter through independent reading rather than by lecture, their time in class spent actively sharing, dialoguing, and problem-solving rather than passively listening. Your job as the instructor is to hold students accountable for good-faith preparation, and to ensure they reason from basic principles rather than merely recall facts and follow procedures.

Every class session should begin with a review of students’ journals on the assigned reading. Have each and every student share what they learned, both in written form by presentation of their journal entries and orally by speaking to the class as a whole. Good-faith effort is the standard of acceptance here, with errors and misconceptions expected since this material is all new to students. Maintaining a thoughtful journal and presenting orally in class are non-negotiable requirements, as the skills of clear writing and public speaking do not grow any other way than by exercising them, and also because these activities help foster critical thinking. You should also write your own journal, both to set a good example for students as well as better understanding their learning experience.

Students must also be held accountable for attempting to solve each and every problem assigned to them in advance of their arrival. Again, the standard of acceptance is good-faith effort, with errors and misconceptions expected. Every student is capable of applying at least one problem-solving strategy to every problem (e.g. identifying relevant principles, sketching a diagram to visualize the problem, simplifying the problem, converting it from quantitative to qualitative or vice-versa, trying limiting cases, etc.). A blank page is unacceptable. You should demonstrate general problem-solving strategies every day, encouraging students to record those strategies in their journals, so that no one can ever claim “I don’t know where to begin” when faced with a new problem.

Exactly how you hold students accountable for their preparatory work is left up to your professional discretion, so long as they indeed do the work. Be flexible and open-minded in your methods, but firm in holding students accountable to reading, writing, speaking, and reasoning.

Class sessions should feature students talking more than you. Your job is to probe their understanding with questions, and to guide their thinking without thinking for them. Socratic dialogue is a good model to follow: question students’ responses whether correct or incorrect, asking them to provide reasons for their answers. The most important question you can ask is, “Why?” Give students enough time to carefully consider the question when answering. Silent problem-solving sessions are good, too, to give students room to think independently while you offer individual assistance. Students should update their journals with any work done in class, treating it as a living document.

When students ask for help, don’t solve the problem for them. Instead, suggest appropriate problem-solving strategies and observe them doing the work. Also, don’t be too quick to confirm their solutions – instead, show them appropriate ways to validate the correctness of their own work (e.g. working the problem backwards, verifying by computer simulation, etc.). Always remember that you are preparing students to be independent learners and problem-solvers, as they will not have your assistance after they complete your course. Far too many students focus on the myopic goals of completing assignments, achieving good grades, passing a course, and earning a degree to the detriment of long-term value found in professional knowledge, skill, and habits. Your job as the instructor is to draw students’ attention toward what matters most.

Experiments should be chosen and designed by students. Do not offer scripted activities, but let your students identify challenging principles from the assigned reading which will be demystified through application. Offer advice regarding safety and practicality, but let them suggest the experimental ideas and procedures. The goal here is to actually practice scientific method, and not merely to complete an activity. Hypotheses should be testable – i.e. liable to confirmation or disproof given unambiguous results. All experimental work should be documented in students’ journals as well.
Complete the following prior to the scheduled session with your instructor:

- Read the short (≈ 8 pages) Journaling chapter of the Principles of Robust Technical Education document in its entirety.
- Decide how you might wish to create your own learning journal for the duration of this course. What software option most appeals to you?

During the scheduled session we will share/discuss the following:

- Your own career aspirations and why you’re taking this course.
- Different levels of Electronics Technician education open to you:
  → The Pathways (modified) option
  → The Full-Time course option
  → Taking transcripted courses at LC State College (Electronics Engineering Technology)
- Career options within the field of Electronics (referencing the Career Guide document as needed).
- Format of the full-time course: “inverted” theory instruction, daily journaling, hands-on experimentation, teach-back sessions, and mock whiteboard technical interviews.
- The next theory session’s topic and the pre-work you’ll need to complete in advance.
Complete the following prior to the scheduled session with your instructor:

- Read the Simplified Tutorial chapter in its entirety.
- Be sure to include in your Journal:
  - A summary in your own words of what the text taught.
  - A question of your own for other students to answer, based on information contained in the text.
  - Any other suggestions listed on the “What to write in your journal” page.
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - Compare and contrast the chain, hydraulic, and electric energy-transfer methods used in the wind turbine / lumber mill scenario.
  - Trace the path of flow in the hydraulic and electric circuits, and describe what happens to the potential energy of the moving entities at different points in each system.
  - What is necessary to construct an electric circuit?
  - What does it mean if something is conserved in a scientific sense, and how does this relate to these energy-transfer systems?

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Full Tutorial chapter:
  - Permanent connections
  - Temporary connections

- Be sure to include in your Journal:
  - A summary in your own words of the different types of electrical connection methods.
  - A question of your own for other students to answer, based on information contained in the text.
  - Any other suggestions listed on the “What to write in your journal” page.

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - In all cases, what is required to form a reliable electrical connection between two or more conductive objects?
  - How come there are so many different ways to connect wires together?
  - What are the advantages and disadvantages of various connection methods?

You will also work with your instructor to install Python programming software if you plan to use your own personal computer, as Python will be tremendously useful for doing calculations on circuits.

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Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Tutorial chapter:
  - Percentages, per-unit, ppm, and ppb
  - Scientific notation
  - Metric prefixes
  - Quantifying error and tolerance

- Read the following section of the Derivations and Technical References chapter:
  - Resistor labeling

- Read the following section of the Programming References chapter:
  - Programming in Python (first two pages only!)

- Be sure to include in your Journal:
  - A summary in your own words of general concepts explained in the text.
  - A question of your own for other students to answer, based on information contained in the text.
  - Any other suggestions listed on the “What to write in your journal” page.

- Define the following terms to the best of your ability, referencing the tutorial in each case:
  - Tolerance
  - “Engineering mode” for a calculator
  - Percentage
  - Power of ten

- Answer all points of the following question(s) found in the learning module:
  - “Plain, metric, and scientific notations” found in the Quantitative Reasoning section of the Questions chapter

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Complete the following prior to the scheduled session with your instructor:

- Read the Full Tutorial chapter in its entirety.
  - A helpful strategy for reading a long tutorial such as this is to first “skim” it to identify its major points and general structure before reading it in depth. If you encounter something you don’t understand on this first pass, continue anyway and it will likely make more sense when you read it a second time (in depth).
  - Since paragraphs encapsulate units of thought, one “skimming” technique is to read just the first sentence or two of every paragraph, saving the reading of each paragraph entirely for the next pass through the text.

- Be sure to include in your Journal:
  - A summary in your own words of general concepts explained in the text.
  - A question of your own for other students to answer, based on information contained in the text.
  - Any other suggestions listed on the “What to write in your journal” page.

- Examine and reflect on the Example: potential in open and shorted circuits section of the Case Tutorial chapter, and answer the following questions:
  - What is an “open” fault guaranteed to prohibit within an electric circuit?
  - What is a “shorted” fault guaranteed to prohibit within an electric circuit?
  - Why does each fault have the effect(s) it has in these circuits?

- Answer all points of the following question found in the learning module:
  - “Applying foundational concepts to a two-lamp circuit” found in the Conceptual Reasoning section of the Questions chapter

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Complete the following prior to the scheduled session with your instructor:

- Read the Full Tutorial chapter in its entirety.
- Be sure to include in your Journal:
  - Update the “glossary” section to expand upon any previously-documented concepts you found applied to this text as well.
  - A question of your own for other students to answer, based on information contained in the text.
  - Any other suggestions listed on the “What to write in your journal” page.
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - List some common examples of electrical sources.
  - List some common examples of electrical loads.
- Answer all points of the following question found in the learning module:
  - “Applying foundational concepts to a solar-powered motor” found in the Conceptual Reasoning section of the Questions chapter

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Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Tutorial chapter:
  → What do all these letters mean?
  → The “equals” symbol
  → Addition and subtraction
  → Multiplication and division
  → Proper order of operations

- Read the following sections of the Case Tutorial chapter:
  → Example: calculator variables
  → Example: balanced equation checking in Python

- Be sure to include in your Journal:
  → A summary in your own words of general concepts explained in the text.
  → A question of your own for other students to answer, based on information contained in the text.
  → Any other suggestions listed on the “What to write in your journal” page.

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → What are some inverse-operation pairs in arithmetic?
  → Why is the order of operations significant to manipulating equations?

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Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Tutorial chapter:
  - Analog versus digital meters
  - Voltage, current, and resistance
  - Series versus parallel connections
  - Measuring voltage
  - Measuring current
  - Measuring resistance

- Be sure to include in your Journal:
  - A summary in your own words of general concepts explained in the text.
  - A question of your own for other students to answer, based on information contained in the text.
  - Any other suggestions listed on the “What to write in your journal” page.

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - How much energy should a meter extract from the circuit being tested?
  - What does it mean if a digital meter registers a negative value?
  - Which electrical quantity(ies) is/are always measured between two points?
  - How do fundamental conservation laws apply to the concepts of voltage, current, and resistance?
  - Why must ammeters and voltmeters be connected differently in circuits?

- Answer all points of the following question found in the learning module:
  - “Applying foundational concepts to multimeter usage” found in the Conceptual Reasoning section of the Questions chapter

Important note: when building circuits with resistors, generally choose resistor values lying between 1 kΩ and 100 kΩ for best results. Resistances less than 1,000 Ohms may result in currents high enough to cause damage, while resistances greater than 100,000 Ohms may result in erroneous voltage measurements due to the “loading” effects of your voltmeter’s insertion resistance. Special cases exist where resistance values outside this 1-100 kΩ range may be appropriate, but in general try to stay within this range!

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Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

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Complete the following prior to the scheduled session with your instructor:

- Read the Full Tutorial chapter in its entirety.
  - A helpful strategy for reading a long tutorial such as this is to first “skim” it to identify its major points and general structure before reading it in depth. If you encounter something you don’t understand on this first pass, continue anyway and it will likely make more sense when you read it a second time (in depth).
  - A helpful strategy for texts applying mathematics is to work through the mathematical examples yourself in order to test your comprehension of what’s being shown, comparing your answer with the text’s in each case.

- Be sure to include in your Journal:
  - An explanation of Ohm’s Law and of Joule’s Law in your own words.
  - A question of your own for other students to answer, based on information contained in the text.
  - Any other suggestions listed on the “What to write in your journal” page.

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - What information must we know in order to compute either voltage, current, or resistance using Ohm’s Law?
  - How is the basic resistor color code formatted to represent resistance values and tolerance?
  - How much electricity is dangerous to the human body?
  - What are the steps commonly followed in a LOTO procedure, and why is each one important?

- Answer all points of the following question found in the learning module:
  - “Voltage, Current, and Resistance in a simple circuit” found in the Quantitative Reasoning section of the Questions chapter

Important note: when building circuits with resistors, generally choose resistor values lying between 1 kΩ and 100 kΩ for best results. Resistances less than 1,000 Ohms may result in currents high enough to cause damage, while resistances greater than 100,000 Ohms may result in erroneous voltage measurements due to the “loading” effects of your voltmeter’s insertion resistance. Special cases exist where resistance values outside this 1-100 kΩ range may be appropriate, but in general try to stay within this range!

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Complete the following prior to the scheduled session with your instructor:

- Read the Tutorial chapter in its entirety.
- Be sure to include in your Journal:
  → A summary in your own words of general concepts explained in the text.
  → A question of your own for other students to answer, based on information contained in the text.
  → Any other suggestions listed on the “What to write in your journal” page.
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → How does a circuit breaker “know” when to trip?
  → Does it matter where a circuit breaker or fuse is placed in a simple circuit?
  → How do we determine the appropriate current rating for a fuse or circuit breaker?
- Answer all points of the following question found in the learning module:
  → “Applying foundational concepts to a fused circuit” found in the Conceptual Reasoning section of the Questions chapter
- Draft a list of teaching topics for the next (Teach-Back) session. Please (1) keep the topics as simple as possible, and only build in complexity if the learners prove their readiness; (2) DO NOT RUSH the learning process; (3) place learners in a role that is as active as possible so you will be able to tell how well they are learning. This same list will prove useful in identifying Whiteboard Interview topics you will be answering in a subsequent session!

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Session 11

In today’s session we will spend the entire time “teaching back” what we’ve been learning to other students. Sharing your knowledge is a proven method of consolidating it, as well as testing yourself to see how well you understand it.

If someone is teaching to you concepts you’re already familiar with, it is important that you play the part of someone innocent of this information. This is easier said than done, but it is important in order to give the “teacher” maximum learning benefit. Recall a time when you were first learning these concepts, before you understood what you understand now, and mentally prepare yourself to ask the same kinds of questions you asked back then. Pose the same kinds of misconceptions you remember having. Purposely make mistakes of the kind you remember making. Let the “teacher” identify these errors for you, and try as best you can to reason through and build upon their instruction alone.

Come to the class session fully prepared with topics ready to present, demonstrations planned, and/or computer simulations already in mind related to what you have recently been learning about electricity and electronics. Below you will find helpful suggestions for instruction:

Foundational Concepts

Any rule, law, principle, or other concept broadly applicable to the analysis of circuits should be considered a “Foundational Concept” worthy of sharing in a teach-back session. If the concept is quantitative in nature, be prepared to illustrate its use with simple numerical examples.

Hands-on Demonstrations

Electricity is invisible, and so practical demonstrations using visible and/or audible indications of electricity are most helpful in clarifying circuit concepts. Where practical, set up each demonstration like a real scientific experiment beginning with the formulation of a testable hypothesis, then run the experiment and collect data to show the validity of the hypothesis. Remember to always survey any potential hazards while planning these demonstrations!

General principles of teaching

• It is always better to teach a few things thoroughly than many things poorly. Keep your lessons short, to the point, and always starting simple. Progress to more complex concepts only if and when your students demonstrate they have understood the simple.
• Ensure all learners actively participate in the lesson, and don’t just passively watch or listen!
• Never rush learning! Always pace your lesson according to how well your students demonstrate they are understanding.
• Plan ahead for your lesson, and decide which role(s) you will play during the session. Spontaneity usually does not work well, especially if you are new to teaching!

Finally, we will brainstorm topics for the next session’s “whiteboard interviews”, where each individual student is challenged to solve problems, analyze circuits, explain concepts, and otherwise demonstrate their learning to the instructor and to all classmates.
Today’s class session will consist of interview-style presentations made to the entire group in front of a whiteboard. The purpose of each “whiteboard interview” is to review important concepts learned over the past theory sessions as well as gain confidence presenting information to and receiving constructive criticism from a critical audience. *Think of this as practice for your future job interviews!*

Your instructor will prepare technical challenges for each of you to answer while standing at a whiteboard. The format is similar to the types of technical interviews common for jobs at SEL. Any concept from any previous class session is “fair game” for these challenges, and together we will brainstorm possible topics during the previous session.

During your “interview” the instructor and any audience members will pose questions. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions. It is okay if you do not know the answer to a question, so long as you explain how you would go about determining what the right answer is: specific ways you would research that answer, and/or experiments you would conduct to empirically determine the answer, etc.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for real job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.
Complete the following prior to the scheduled session with your instructor:

- Read the Simplified Tutorial chapter in its entirety.
  → Work through all quantitative examples yourself, to prove you understand the math.
- Update your Journal as usual, taking suggestions from the “What to write in your journal” page. Note: prompts to update your Journal will not appear in any future session descriptions, as this is a base-line expectation throughout the course.
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → How do individual component voltages relate to total (source) voltage in a series network, and why is this so?
  → How do individual component currents relate to total (source) current in a series network, and why is this so?
  → How do individual component resistances relate to total resistance in a series network, and why is this so?
- Answer all points of the following question found in the learning module:
  → “Identifying series circuits” found in the Conceptual Reasoning section of the Questions chapter.

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the Full Tutorial chapter in its entirety.
  → Work through all quantitative examples yourself, to prove you understand the math.
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → Why, exactly, is current the same at any given time through all series-connected components?
  → Explain in your own words each of the steps taken to analyze one of the example circuits in the Full Tutorial.
  → Summarize all the essential properties of a series network.
- Answer all points of the following question found in the learning module:
  → “Explaining the meaning of calculations” found in the Conceptual Reasoning section of the Questions chapter.

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the Simplified Tutorial chapter in its entirety.
  → Work through all quantitative examples yourself, to prove you understand the math

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → How do individual component voltages relate to total (source) voltage in a parallel network, and why is this so?
  → How do individual component currents relate to total (source) current in a parallel network, and why is this so?
  → How do individual component resistances relate to total resistance in a parallel network, and why is this so?

- Answer all points of the following question found in the learning module:
  → “Identifying parallel circuits” found in the Conceptual Reasoning section of the Questions chapter

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.

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Complete the following prior to the scheduled session with your instructor:

- **Read the Full Tutorial chapter in its entirety.**
  - Work through all quantitative examples yourself, to prove you understand the math.
- **Answer the following questions to the best of your ability, referencing the tutorial in each case:**
  - What is a scientifically accurate definition for voltage and also its unit of measurement?
  - What is a scientifically accurate definition for current and also its unit of measurement?
  - What is a scientifically accurate definition for power and also its unit of measurement?
  - Why, exactly, is voltage the same at any given time across all parallel-connected components?
  - Explain in your own words each of the steps taken to analyze one of the example circuits in the Full Tutorial.
  - Summarize all the essential properties of a parallel network.
- **Answer all points of the following question found in the learning module:**
  - “Explaining the meaning of calculations” found in the Conceptual Reasoning section of the Questions chapter

**Session Expectations:**

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the Full Tutorial chapter in its entirety.
  → Work through all quantitative examples yourself, to prove you understand the math
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → What are the fundamental properties of any series network, and why are these so?
  → What are the fundamental properties of any parallel network, and why are these so?
  → What is Kirchhoff’s Voltage Law useful for predicting?
  → Why is Kirchhoff’s Voltage Law true – in other words, what is the fundamental conservation law underpinning KVL?
  → What do “ground” and “bus” symbols represent in a schematic diagram?
- Answer all points of the following question found in the learning module:
  → “Tracing KVL loops in a multi-source circuit” found in the Quantitative Reasoning section of the Questions chapter

By this point in time, you should feel comfortable doing the following:

- Proper multimeter usage (voltmeter, ammeter, ohmmeter)
- Constructing circuits using both breadboards and terminal blocks
- Using the metric prefixes milli, micro, and kilo, as well as their associated powers-of-ten
- Using Python or a scientific calculator to do Ohm’s Law and Joule’s Law calculations
- Clearly documenting your circuit predictions and experimental results

If not, use your circuit-building time to practice those tasks you’re least comfortable with!

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the Full Tutorial chapter in its entirety.  
  → Work through all quantitative examples yourself, to prove you understand the math.
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → What are the fundamental properties of any series network, and why are these so? 
  → What are the fundamental properties of any parallel network, and why are these so? 
  → What is Kirchhoff’s Current Law useful for predicting? 
  → Why is Kirchhoff’s Current Law true – in other words, what is the fundamental conservation law underpinning KCL?
- Answer all points of the following question found in the learning module:
  → “Currents in a large resistor network” found in the Quantitative Reasoning section of the Questions chapter

By this point in time, you should feel comfortable doing the following:

- Proper multimeter usage (voltmeter, ammeter, ohmmeter) 
- Constructing circuits using both breadboards and terminal blocks 
- Using the metric prefixes milli, micro, and kilo, as well as their associated powers-of-ten 
- Using Python or a scientific calculator to do Ohm’s Law and Joule’s Law calculations 
- Clearly documenting your circuit predictions and experimental results

If not, use your circuit-building time to practice those tasks you’re least comfortable with!

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the Simplified Tutorial chapter in its entirety.
  → Work through all quantitative examples yourself, to prove you understand the math

- Peruse the Check-list of Foundational Concepts located on the last page of this course document and explain each concept in detail, as well as provide specific examples of how some of these concepts were applied in the Simplified Tutorial.

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → How may any series-parallel network be reduced step-by-step to a simpler equivalent network?
  → Demonstrate the mathematical calculations necessary for steps taken analyzing the series-parallel example circuit shown in the Simplified Tutorial

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.

file wte_0025
Complete the following prior to the scheduled session with your instructor:

- Read the Full Tutorial chapter in its entirety.
  → Work through all quantitative examples yourself, to prove you understand the math
- Peruse the Check-list of Foundational Concepts located on the last page of this course document and explain each concept in detail, as well as provide specific examples of how some of these concepts were applied in the Full Tutorial.
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → What does it mean to say that problem-solving strategies often substitute tedium for complexity?
  → Explain in your own words how a series-parallel resistor network may be reduced to a single equivalent resistance, referring to one of the example problems in the tutorial to illustrate
  → Explain in your own words how a reduced series-parallel resistor network may be expanded back into its original form with all resistor voltages and currents solved, referring to one of the example problems in the tutorial to illustrate
- Time permitting, analyze circuit #1 in the “Mixed-source circuits” question contained in the Quantitative Reasoning section of the Questions chapter. It is possible to solve for all voltages and currents in this network using just KVL, KCL, Ohm’s Law, and the properties of series and parallel networks!

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Tutorial chapter:
  - Electric versus magnetic fields
  - Electromagnetism
  - The right-hand rule
  - Electromagnetic induction

- Define the following terms to the best of your ability, referencing the tutorial in each case:
  - Electromagnetism
  - Electromagnetic induction
  - Faraday’s Law

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - What type(s) of matter does an electric field act upon?
  - What type(s) of matter does a magnetic field act upon?
  - How may we produce a magnetic field?
  - Demonstrate how the Right Hand Rule applies to the Tutorial examples
  - How may we generate electricity using a magnetic field?

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Tutorial chapter:
  - What is a relay?
  - Contact arrangements
  - Relay ratings
  - Solid-state relays

- Define the following terms to the best of your ability, referencing the tutorial in each case:
  - Poles versus throws
  - NO versus NC contacts
  - “Common” terminal

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - How does a relay differ in operation from a manually-actuated switch?
  - What are some practical uses for relays?
  - How does the energization state of a relay coil relate to its contact’s status?

- Draft a list of teaching topics for the next (Teach-Back) session. Please (1) keep the topics as simple as possible, and only build in complexity if the learners prove their readiness; (2) DO NOT RUSH the learning process; (3) place learners in a role that is as active as possible so you will be able to tell how well they are learning. This same list will prove useful in identifying Whiteboard Interview topics you will be answering in a subsequent session!

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
In today’s session we will spend the entire time “teaching back” what we’ve been learning to other students. Sharing your knowledge is a proven method of consolidating it, as well as testing yourself to see how well you understand it.

If someone is teaching to you concepts you’re are already familiar with, it is important that you *play the part* of someone innocent of this information. This is easier said than done, but it is important in order to give the “teacher” maximum learning benefit. Recall a time when you were first learning these concepts, before you understood what you understand now, and mentally prepared yourself to ask the same kinds of questions you asked back then. Pose the same kinds of misconceptions you remember having. Purposely make mistakes of the kind you remember making. Let the “teacher” identify these errors for you, and try as best you can to reason through and build upon their instruction alone.

Come to the class session fully prepared with topics ready to present, demonstrations planned, and/or computer simulations already in mind related to what you have recently been learning about electricity and electronics. Below you will find helpful suggestions for instruction:

**Foundational Concepts**

Any rule, law, principle, or other concept broadly applicable to the analysis of circuits should be considered a “Foundational Concept” worthy of sharing in a teach-back session. If the concept is quantitative in nature, be prepared to illustrate its use with simple numerical examples.

**Hands-on Demonstrations**

Electricity is invisible, and so practical demonstrations using visible and/or audible indications of electricity are most helpful in clarifying circuit concepts. Where practical, set up each demonstration like a real scientific experiment beginning with the formulation of a testable hypothesis, then run the experiment and collect data to show the validity of the hypothesis. Remember to always survey any potential hazards while planning these demonstrations!

**General principles of teaching**

- It is always better to teach a few things thoroughly than many things poorly. Keep your lessons short, to the point, and always starting simple. Progress to more complex concepts only if and when your students demonstrate they have understood the simple.
- Ensure all learners actively participate in the lesson, and don’t just passively watch or listen!
- Never rush learning! Always pace your lesson according to how well your students demonstrate they are understanding.
- *Plan ahead* for your lesson, and decide which role(s) you will play during the session. Spontaneity usually does not work well, especially if you are new to teaching!

Finally, we will brainstorm topics for the next session’s “whiteboard interviews”, where each individual student is challenged to solve problems, analyze circuits, explain concepts, and otherwise demonstrate their learning to the instructor and to all classmates.
Today’s class session will consist of interview-style presentations made to the entire group in front of a whiteboard. The purpose of each “whiteboard interview” is to review important concepts learned over the past theory sessions as well as gain confidence presenting information to and receiving constructive criticism from a critical audience. Think of this as practice for your future job interviews!

Your instructor will prepare technical challenges for each of you to answer while standing at a whiteboard. The format is similar to the types of technical interviews common for jobs at SEL. Any concept from any previous class session is “fair game” for these challenges, and together we will brainstorm possible topics during the previous session.

During your “interview” the instructor and any audience members will pose questions. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions. It is okay if you do not know the answer to a question, so long as you explain how you would go about determining what the right answer is: specific ways you would research that answer, and/or experiments you would conduct to empirically determine the answer, etc.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for real job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.
Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Tutorial chapter:
  - Electric shock and burn hazards
  - Hot, neutral, and ground power conductors
  - The National Electrical Code (NFPA 70)

- Read the following section of the Derivations and Technical References chapter:
  - Ground in electric and electronic circuits

- Peruse the Check-list of Foundational Concepts located on the last page of this course document and explain how these concepts apply to electrical safety.
  - Explain in your own words the hazardous ("shocked") versus non-hazardous ("not shocked") scenarios illustrated in the Tutorial.

- Define the following terms to the best of your ability, referencing the tutorial in each case:
  - Differentiate between voltage, current, resistance, energy, and power
  - Electrically common points
  - Disconnect switch
  - Bonding cable
  - Hot, Neutral, and Ground conductors

- Time permitting, analyze another one of the circuits shown in the “Mixed-source circuits” question contained in the Quantitative Reasoning section of the Questions chapter of the Series-Parallel Circuits learning module (https://ibiblio.org/kuphaldt/socratic/model/mod_seriesparallel.pdf). It is possible to solve for all voltages and currents in these multi-source networks using only the Foundational Concepts you have learned so far (e.g. KVL, KCL, Ohm’s Law, and the properties of series and parallel networks)!

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Session 26

Source text – Capacitance and Inductance learning module


Complete the following prior to the scheduled session with your instructor:

- Read the Simplified Tutorial chapter in its entirety.
- Read the following sections of the Case Tutorial chapter:
  → Example: capacitor storing and releasing energy
  → Example: inductor storing and releasing energy
- Define the following terms to the best of your ability, referencing the tutorial in each case:
  → Sources versus loads
  → Capacitance
  → Inductance
  → Conservation of Energy
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → What is necessary in order to create capacitance in a system?
  → What is necessary in order to create inductance in a system?
  → What are some practical applications of capacitance?
  → What are some practical applications of inductance?

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Simplified Tutorial chapter:
  → A graphical voltmeter
  → Oscilloscope probes and grounding
  → Sensitivity and amplitude measurement
  → Timebase and frequency measurement
- Read the following sections of the Case Tutorial chapter:
  → First-time oscilloscope experiment ideas
- Define the following terms to the best of your ability, referencing the tutorial in each case:
  → Sensitivity
  → Timebase
  → Division
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → What is represented on the vertical axis of an oscilloscope display?
  → What is represented on the horizontal axis of an oscilloscope display?
  → How can you calculate the frequency of an AC signal on an oscilloscope display?

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the Tutorial chapter in its entirety.
  → List and define at least three important principles from the text (see the “Foundational concepts” subsection of the Conceptual Reasoning section of the Questions chapter for ideas).
  → Write a question of your own based on information contained in the text.
- Define the following terms to the best of your ability, referencing the tutorial in each case:
  → Dielectric
  → Time constant
  → Polarization

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the Tutorial chapter in its entirety.
  - List and define at least three important principles from the text (see the “Foundational concepts” subsection of the Conceptual Reasoning section of the Questions chapter for ideas).
  - Write a question of your own based on information contained in the text.

- Define the following terms to the best of your ability, referencing the tutorial in each case:
  - Permeability
  - Time constant
  - Magnetic saturation

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the Tutorial chapter in its entirety.
  → Answer at least three of the questions found in the Introduction chapter
  → Write a question of your own based on information contained in the text

- Analyze some of the circuits shown in the “Mixed-source circuits with capacitors and inductors” question contained in the Quantitative Reasoning section of the Questions chapter of the Series-Parallel Circuits learning module (https://ibiblio.org/kuphaldt/socratic/model/mod_seriesparallel.pdf). It is possible to solve for all voltages and currents in these multi-source networks using only the Foundational Concepts you have learned so far (e.g. KVL, KCL, Ohm’s Law, and the properties of series and parallel networks)!

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the Simplified Tutorial chapter in its entirety.
  → Answer at least three of the questions found in the Introduction chapter
  → Write a question of your own based on information contained in the text
- Peruse the Check-list of Foundational Concepts located on the last page of this course document and explain each concept in detail, as well as provide specific examples of how some of these concepts apply to transformers.
- Answer all points of the following question found in the learning module:
  → “Basic transformer calculations” found in the Quantitative Reasoning section of the Questions chapter

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Full Tutorial chapter:
  - Triggering
  - Measuring phase shift

- Define the following terms to the best of your ability, referencing the tutorial in each case:
  - Triggering
  - Normal versus Auto triggering
  - Ripple
  - Period

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - How do you properly set the trigger controls on an oscilloscope to display a signal?
  - Choose any one of the oscillographs shown in the “Measuring waveform parameters” questions in the “Quantitative Reasoning” section of the Questions chapter and attempt to calculate its parameters.

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

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Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Tutorial chapter:
  → AC-DC power conversion
  → Diodes
  → Simple rectifier circuits
  → Center-tapped transformer rectifiers
  → Ripple

- Define the following terms to the best of your ability, referencing the tutorial in each case:
  → Half-wave rectification
  → Full-wave rectification
  → Ripple

- Peruse the Check-list of Foundational Concepts located on the last page of this course document and explain each concept in detail, as well as provide specific examples of how some of these concepts were applied in the Tutorial.

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → What is the purpose of a diode in a rectifier circuit?
  → What are some methods for reducing the amount of ripple at the output of a rectifier circuit?

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

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Complete the following prior to the scheduled session with your instructor:

- Read the Tutorial chapter in its entirety.
  → Answer at least three of the questions found in the Introduction chapter
  → Write a question of your own based on information contained in the text

- Peruse the Check-list of Foundational Concepts located on the last page of this course document and explain each concept in detail, as well as provide specific examples of how some of these concepts apply to power supply circuits.

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

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Session 35

In today’s session we will spend the entire time “teaching back” what we’ve been learning to other students. Sharing your knowledge is a proven method of consolidating it, as well as testing yourself to see how well you understand it.

If someone is teaching you concepts you’re already familiar with, it is important that you play the part of someone innocent of this information. This is easier said than done, but it is important in order to give the “teacher” maximum learning benefit. Recall a time when you were first learning these concepts, before you understood what you now understand, and mentally prepare yourself to ask the same kinds of questions you asked back then. Pose the same kinds of misconceptions you remember having. Purposely make mistakes of the kind you remember making. Let the “teacher” identify these errors for you, and try as best you can to reason through and build upon their instruction alone.

Come to the class session fully prepared with topics ready to present, demonstrations planned, and/or computer simulations already in mind related to what you have recently been learning about electricity and electronics. Below you will find helpful suggestions for instruction:

Foundational Concepts

Any rule, law, principle, or other concept broadly applicable to the analysis of circuits should be considered a “Foundational Concept” worthy of sharing in a teach-back session. If the concept is quantitative in nature, be prepared to illustrate its use with simple numerical examples.

Hands-on Demonstrations

Electricity is invisible, and so practical demonstrations using visible and/or audible indications of electricity are most helpful in clarifying circuit concepts. Where practical, set up each demonstration like a real scientific experiment beginning with the formulation of a testable hypothesis, then run the experiment and collect data to show the validity of the hypothesis. Remember to always survey any potential hazards while planning these demonstrations!

General principles of teaching

• It is always better to teach a few things thoroughly than many things poorly. Keep your lessons short, to the point, and always starting simple. Progress to more complex concepts only if and when your students demonstrate they have understood the simple.
• Ensure all learners actively participate in the lesson, and don’t just passively watch or listen!
• Never rush learning! Always pace your lesson according to how well your students demonstrate they are understanding.
• Plan ahead for your lesson, and decide which role(s) you will play during the session. Spontaneity usually does not work well, especially if you are new to teaching!

Finally, we will brainstorm topics for the next session’s “whiteboard interviews”, where each individual student is challenged to solve problems, analyze circuits, explain concepts, and otherwise demonstrate their learning to the instructor and to all classmates.
Today’s class session will consist of interview-style presentations made to the entire group in front of a whiteboard. The purpose of each “whiteboard interview” is to review important concepts learned over the past theory sessions as well as gain confidence presenting information to and receiving constructive criticism from a critical audience. *Think of this as practice for your future job interviews!*

Your instructor will prepare technical challenges for each of you to answer while standing at a whiteboard. The format is similar to the types of technical interviews common for jobs at SEL. Any concept from any previous class session is “fair game” for these challenges, and together we will brainstorm possible topics during the previous session.

During your “interview” the instructor and any audience members will pose questions. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions. It is okay if you do not know the answer to a question, so long as you explain how you would go about determining what the right answer is: specific ways you would research that answer, and/or experiments you would conduct to empirically determine the answer, etc.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for real job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.
Complete the following prior to the scheduled session with your instructor:

- Read the Tutorial chapter in its entirety.
  → Answer at least three of the questions found in the Introduction chapter
  → Write a question of your own based on information contained in the text

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the Tutorial chapter in its entirety.
  - Answer at least three of the questions found in the Introduction chapter
  - Write a question of your own based on information contained in the text

- Answer all points of the following question(s) found in the learning module:
  - “Associating logic functions with relay circuit” found in the Quantitative Reasoning section of the Questions chapter
  - “Identifying possible faults in a relay circuit” found in the Diagnostic Reasoning section of the Questions chapter

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Tutorial chapter:
  - Bicycle headlamp alarm
  - Logic gate limitations
  - Logic levels

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - Run some “thought experiments” on the bicycle headlamp alarm circuits to prove, step-by-step, how the alarm only activates under the proper conditions

- Answer all points of the following question found in the learning module:
  - “Diode-resistor logic gates” found in the Conceptual Reasoning section of the Questions chapter

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the Simplified Tutorial chapter in its entirety.
- Read the following sections of the Case Tutorial chapter:
  - Example: NAND function in a PLC
  - Example: simple PLC comparisons
- Go to AutomationDirect.com and download documents on the CLICK series of programmable logic controllers, especially the model C0-00DD1-D or C0-00DD2-D basic PLC modules, to answer the following questions:
  - Explain how switches are connected to input terminals on the PLC to send discrete (on/off) signals to the PLC
  - Explain how loads are connected to output terminals on the PLC to receive discrete (on/off) signals from the PLC

*Note: in today’s session we will devote ample time to hands-on experimentation with the PLCs, to learn how to use the programming software, to learn how to wire input and output terminals to external components, and to learn how the PLC interprets and processes these signals.*

**Session Expectations:**

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Tutorial chapter:
  → Microcontrollers and PLCs
  → Logical OR function
  → Logical AND function
  → Logical NOT function

- Read the following sections of the Case Tutorial chapter:
  → Example: Arduino 3-input logic functions

- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → How do microcontrollers differ from PLCs in form?
  → How do microcontrollers differ from PLCs in function?
  → How do microcontrollers differ from PLCs in terms of programming languages?
  → What is the “normal” status of a switch contact?

Note: in today’s session we will devote ample time to hands-on experimentation with Arduino microcontrollers and with PLCs, to learn how to use the programming software, to learn how to wire input and output terminals to external components, and to learn how these devices interpret and process these signals.

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Complete the following prior to the scheduled session with your instructor:

- Read the following sections of the Tutorial chapter:
  - Numbers versus numeration
  - Unsigned integers
  - Shorthand representations of digital words
- Read the following section of the Programming References chapter:
  - Numeration formats in Python and C++
- Read the “A binary resistance box” section of the Historical References chapter and answer the following questions:
  - Where do you find any properties of series networks applied to these “resistance box” designs?
  - Where do you find any properties of parallel networks applied to these “resistance box” designs?
- Answer the following questions to the best of your ability, referencing the assigned reading(s) in each case:
  - What are some alternatives to our common decimal-based numeration system?
  - Why is binary the preferred numeration system for digital electronic circuits?
  - What practical purpose does octal or hexadecimal serve for human beings working with binary quantities?
- Answer all points of the following question found in the learning module:
  - “Binary to decimal and hex conversions” found in the Quantitative Reasoning section of the Questions chapter

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

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Complete the following prior to the scheduled session with your instructor:

- Read the Simplified Tutorial chapter in its entirety.
- Answer all points of the following question(s) found in the learning module:
  - “Applying foundational concepts to ???” found in the Conceptual Reasoning section of the Questions chapter
  - “???” found in the Quantitative Reasoning section of the Questions chapter
  - “???” found in the Diagnostic Reasoning section of the Questions chapter
- Answer the following questions to the best of your ability, referencing the tutorial in each case:

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

After discussing the assigned text(s) and Journal entries, we will transition to hands-on experiments applying concepts learned in this and previous sessions. Students and instructor together will select appropriate experimental ideas, and then students will work alone or in small groups to run these experiments. Good sources of experiment ideas include the assigned Tutorial readings as well as Case Tutorial sections from the same learning module.
Session 44

Source text – Programmable Control Devices learning module


Complete the following prior to the scheduled session with your instructor:

• Read the following sections of the Tutorial chapter:
  → Off-delay timer function
  → On-delay timer function

• Read the following sections of the Case Tutorial chapter:
  → Example: Arduino off-delay timer
  → Example: Arduino on-delay timer

• Answer the following questions to the best of your ability, referencing the tutorial in each case:
  → How does an “off-delay” function differ from an “on-delay” function?
  → What is a routine in a computer program, also known as a subroutine or a function?
  → Identify multiple ways to implement time-delay functions using a microcontroller
  → Explain how you could calculate the amount of time delay provided by a logic gate with a resistor-capacitor timing network connected to the gate’s input

Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

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Complete the following prior to the scheduled session with your instructor:

- Read the Simplified Tutorial chapter in its entirety.
- Answer all points of the following question(s) found in the learning module:
  - “Applying foundational concepts to ???” found in the Conceptual Reasoning section of the Questions chapter
  - “???” found in the Quantitative Reasoning section of the Questions chapter
  - “???” found in the Diagnostic Reasoning section of the Questions chapter
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  - 
  - 
  - 

**Session Expectations:**

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Complete the following prior to the scheduled session with your instructor:

- Read the Simplified Tutorial chapter in its entirety.
- Answer all points of the following question(s) found in the learning module:
  - “Applying foundational concepts to ???” found in the Conceptual Reasoning section of the Questions chapter
  - “???” found in the Quantitative Reasoning section of the Questions chapter
  - “???” found in the Diagnostic Reasoning section of the Questions chapter
- Answer the following questions to the best of your ability, referencing the tutorial in each case:
  
Session Expectations:

Thoroughly read the assigned text(s) and update your Journal with your own reflections and your own questions prior to the start of class. Make a good-faith effort to solve every assigned problem on your own prior to class as well. Be prepared to electronically share your Journal entry with the class. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles. Mastery of these principles only comes through practice, and so the primary purpose of class time is to apply them and to recover from mistakes when they occur.

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Come to the class session fully prepared with topics ready to present, demonstrations planned, and/or computer simulations already in mind related to what you have recently been learning about electricity and electronics. Below you will find helpful suggestions for instruction:

**Foundational Concepts**

Any rule, law, principle, or other concept broadly applicable to the analysis of circuits should be considered a “Foundational Concept” worthy of sharing in a teach-back session. If the concept is quantitative in nature, be prepared to illustrate its use with simple numerical examples.

**Hands-on Demonstrations**

Electricity is invisible, and so practical demonstrations using visible and/or audible indications of electricity are most helpful in clarifying circuit concepts. Where practical, set up each demonstration like a real scientific experiment beginning with the formulation of a testable hypothesis, then run the experiment and collect data to show the validity of the hypothesis. Remember to always survey any potential hazards while planning these demonstrations!

**General principles of teaching**

- It is always better to teach a few things thoroughly than many things poorly. Keep your lessons short, to the point, and always starting simple. Progress to more complex concepts only if and when your students demonstrate they have understood the simple.
- Ensure all learners actively participate in the lesson, and don’t just passively watch or listen!
- Never rush learning! Always pace your lesson according to how well your students demonstrate they are understanding.
- *Plan ahead* for your lesson, and decide which role(s) you will play during the session. Spontaneity usually does not work well, especially if you are new to teaching!

Finally, we will brainstorm topics for the next session’s “whiteboard interviews”, where each individual student is challenged to solve problems, analyze circuits, explain concepts, and otherwise demonstrate their learning to the instructor and to all classmates.
Today’s class session will consist of interview-style presentations made to the entire group in front of a whiteboard. The purpose of each “whiteboard interview” is to review important concepts learned over the past theory sessions as well as gain confidence presenting information to and receiving constructive criticism from a critical audience. *Think of this as practice for your future job interviews!*

Your instructor will prepare technical challenges for each of you to answer while standing at a whiteboard. The format is similar to the types of technical interviews common for jobs at SEL. Any concept from any previous class session is “fair game” for these challenges, and together we will brainstorm possible topics during the previous session.

During your “interview” the instructor and any audience members will pose questions. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions. It is okay if you do not know the answer to a question, so long as you explain how you would go about determining what the right answer is: specific ways you would research that answer, and/or experiments you would conduct to empirically determine the answer, etc.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for real job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.
Check-list of Foundational Concepts

- Conservation of Energy
- Conservation of Electric Charge
- Behavior of sources versus loads
- Ohm's Law
- Joule's Law
- Effects of opens versus shorts
- Properties of series networks
- Properties of parallel networks
- Kirchhoff's Voltage Law
- Kirchhoff's Current Law