

Integrating Sociotechnical Issues into Introductory Circuits Courses: Seven Emerging Modules

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Abstract—Integrating sociotechnical content into foundational engineering courses is a critical, but often overlooked, goal of engineering education. To accomplish this goal, we developed several one-hour modules for the Introduction to Circuits course that include learning objectives, pre-class activities, detailed class guides (with presentation slides, in-class activities, and instructor talking points), and post-class homework and exam questions. We have successfully implemented two initial modules in small and large classes, and in Summer 2024 we collaborated with a diverse cohort of graduate students from across the U.S. to create seven new modules. The modules address issues including sustainable development and energy efficiency, environmental and social impacts of lithium mining, global energy access, and CO₂ emissions. In this paper, we describe the seven emerging modules.

Keywords—course design, circuits, electrical engineering, social responsibility

I. INTRODUCTION

Integrating sociotechnical content into foundational engineering courses is a critical, but often overlooked, goal of engineering education. Engineering courses are traditionally taught from a purely technical perspective, but real problems and society’s grand challenges are more sociotechnical in nature. Accreditation bodies require engineering curricula to include some elements of social responsibility (e.g., ABET [1] and the European Network for Accreditation in Engineering Education [2]), as do codes of ethics of professional societies such as IEEE [3], the National Society of Professional Engineers [4], and Engineers Europe [5]. However, engineering instructors often face challenges integrating the sociotechnical aspects of engineering into their courses. Common challenges include that they feel ill-prepared to address social issues, they have little experience on which to draw, and they lack the time needed to design good course material. Instructors need easy-to-adapt materials.

As two electrical engineering (EE) faculty members with decades of teaching experience and with funding from a U.S. National Science Foundation grant, we are addressing these challenges by developing several one-hour modules for the Introduction to Circuits course. The modules reinforce the technical content of the course, they emphasize different social issues, and they are linked to students’ lives and experiences through, for instance, connections with mainstream movies like *Black Panther* [6] and with issues in the current news such as electric vehicle (EV) batteries. Each module contains potential

learning objectives, pre-class activities, a detailed class guide (with presentation slides, in-class activities, and instructor talking points), and post-class homework and exam questions to aid engineering instructors in incorporating sociotechnical content into their courses. Consistent with backward course design principles [7], the learning objectives for our modules are aligned with both the instructional activities and the class assessments. Related references are included for instructors or students who want to learn more about the topic.

We have successfully implemented two initial modules in small and large classes. The first module connects with the technical course topic of capacitors and introduces social issues related to mining conflict minerals in the Democratic Republic of the Congo [8], [9]. The module includes learning objectives for both the technical and social content (e.g., define conflict minerals; describe options for engineers concerned with their social implications). The second module connects with the voltage divider principle in circuits, and it introduces the concept of the circular economy as a potential solution to some of the social issues related to EV battery life [10], [11]. This module also includes both technical and social learning objectives (e.g., design a voltage divider for a DC source to illustrate repurposing EV battery packs; describe societal risks introduced by recycling EV batteries that could be alleviated by applying circular economy principles). Both modules were tested initially in a small interdisciplinary engineering course at a small private institution and, after being refined, they were tested a second time in a large electrical /computer engineering course at a large public institution. Student response to both modules was positive (e.g., [12], [13], [14]), suggesting that additional modules may be received well by students and instructors.

In Summer 2024, we collaborated with a diverse cohort of seven electrical engineering and engineering education graduate students from across the U.S. to develop seven new modules. At a two-day in-person meeting in May 2024, the cohort participated in the conflict minerals module, learned about guidelines for developing sociotechnical modules [15], reviewed the course content and learning objectives for the typical Introduction to Circuits course, and learned about backward course design principles [7]. They brainstormed topics for new sociotechnical modules and subsequently worked in pairs over the summer to develop learning objectives, pre-class activities, detailed class guides (with presentation slides, in-class activities, and instructor talking points), and post-class homework and exam questions for seven sociotechnical

modules. They presented these modules in August 2024 online to the entire cohort and refined them over the next month. Some students piloted their modules in Fall 2024. In this paper, we describe these seven emerging modules.

II. OVERVIEW OF EMERGING SOCIOTECHNICAL MODULES

We have seven new modules ready for testing. They address a range of social issues, including sustainable development and energy efficiency; energy burden; differential energy access and stability across the globe; real-world voltage sources; environmental and social impacts of lithium mining; power prioritization in hospital settings; and CO₂ emissions and climate change. The social issues are connected to various circuits topics, such as power and energy, open and short circuits, and complex power. Each module includes learning objectives for both the technical and social content of the course (as outlined in Table I), as well as pre-class activities, a detailed class guide (with presentation slides, in-class activities, and instructor talking points), and post-class homework and exam questions.

A. Energy efficiency

This module encourages students to identify strategies related to energy efficiency that they, as future engineers, could implement to meet sustainable development goals. It aligns with the topics in circuits of energy consumption, power absorption, and efficiency in electrical circuits, and it helps students explore the broader impacts of their engineering decisions on society and the environment.

As a pre-class activity, students watch videos and read material about the Sustainable Development Goals (SDGs), particularly *SDG 7: Affordable and Clean Energy*, and to learn about energy efficiency and its importance in reducing energy consumption. Students answer several related multiple-choice questions and identify local initiatives that support SDG 7.

During class, the instructor reviews the pre-class activity, presents a brief history of the SDGs emphasizing the importance of ensuring access to affordable, reliable, sustainable, and modern energy for all, and describes the role of energy efficiency in achieving this goal. Next, the instructor explains energy efficiency, including the concepts of energy (measured in joules) and power (energy over time), derives related formulas, and works through two example calculation of power generated by a DC motor while discussing the significance of efficiency in engineering design. The instructor then introduces real-world efforts in Philadelphia, Pennsylvania in the U.S. to increase energy efficiency through a public lighting initiative to use LED streetlights and presents policy examples designed to promote energy efficiency through regulations, information, and incentives. Students discuss the policy examples in small groups and identify strategies engineers could use to meet sustainable development objectives.

The module includes several post-class homework and exam questions. Students generate solutions to enhance energy efficiency, develop strategies to implement SDG 7 in various industries, and calculate energy and cost savings for replacing streetlights with LED technology in a different city.

B. Energy burden

This module helps students define and address energy burden, and it aligns with the topics in circuits of power and energy. Students learn to analyze power and energy relationships, calculate energy consumption and costs, and explore socioeconomic impacts of high energy burden. They identify ways to reduce energy burden through energy-efficient solutions and policies that can support sustainable development and enhance the well-being of economically disadvantaged households.

As a pre-class activity, students listen to a podcast about unveiling hidden energy poverty and answer related questions about energy insecurity. They also find information about their local utility provider and use appliance data sheets to estimate the energy consumption of household appliances they use.

In class, the instructor reviews the pre-class activity, including definitions and examples of energy poverty and energy insecurity, discusses the difference between power and energy, and calculates energy consumption using power ratings of appliances and duration of use. Next, the instructor discusses sample electricity bills and household costs, defines energy burden, and introduces the online Low-Income Energy Affordability Data (LEAD) Tool for exploring energy expenditures and housing characteristics by geographic area in the U.S. Students then discuss the ill effects of high energy burden, and the instructor describes ways engineers, consumers, and policymakers can reduce energy burden. Students calculate the energy burden of hypothetical households, discuss the implications of varying income levels, estimate monthly electricity bills, and identify energy savings in an example involving lighting systems.

This module includes five possible homework and exam questions. Two short answer problems are about energy burden and time-of-use pricing. A third problem requires students to compare compact fluorescent lamps and LEDs for energy efficiency, monthly savings, payback period, and lifetime replacement costs. A fourth problem has students use the LEAD tool to identify high energy burden census tracts and suggest pathways to reduce energy burden. The final problem has students calculate the electricity bill using a time-of-use pricing model and analyze the benefits.

C. Energy priority

This module introduces students to power distribution issues that arise during planned and unplanned outages and serves as a case study for explaining technical concepts such as open circuits, short circuits, and switches. It addresses social issues related to geographic variation in energy access and stability and encourages a critical analysis of energy distribution during emergencies. The goal of this module is to help students understand the broader social, economic, and political impacts of engineering problems.

Before class, students listen to a podcast about the effects of Superstorm Sandy on vulnerable populations and answer related open-ended questions. These activities help students learn about consequences of power outages and reflect on whose voices are traditionally heard and unheard during such events.

Class begins with a mindfulness exercise, followed by a review of pre-class activities. Next, the instructor explains open and short circuits and discusses planned and unplanned power outages as well as the importance of equitable power distribution. In pairs, students discuss prioritizing power distribution to hospitals, farms, industry, and homes during emergencies. The class then considers “social vulnerability” and its relevance to power outages, examines data from the U.S. Centers for Disease Control and Prevention, and uses the social vulnerability index to explore regional differences. Finally, student teams design a power distribution system for emergency situations, and the instructor summarizes key concepts and encourages students to reflect on the broader impacts of engineering decisions.

There are two post-class questions for this module. First, students design a circuit to ensure that critical loads are powered during an emergency when using a backup generator with limited capacity. Second, they design a power distribution circuit with constraints on the number of building systems, switches, and sources used, prioritizing specific building systems and justifying design choices.

D. Real-world voltage sources

This module is connected to topics in circuits of voltage, charge, current, and resistance, and it introduces social issues related to real-world voltage sources. Students learn to evaluate benefits and drawbacks of different voltage sources, considering efficiency, environmental impact, and ethical implications.

Before class, students watch a video about electric vehicles powered by hydrogen fuel cells and by batteries and the efficiency of both, and they solve related problems. Two other videos about the theory of voltaic cells and the greenhouse effect are optional.

In class, the instructor summarizes key points from the pre-class video, reviews Ohm’s Law, resistors, ideal sources, and I-V curves for resistive elements, and introduces and compares lithium-ion batteries and hydrogen fuel cells. Students then discuss the advantages and disadvantages of lithium-ion batteries and hydrogen fuel cells, including technical and ethical trade-offs. The instructor highlights comparisons such as efficiency and carbon emissions and presents a hydrogen fuel cell-powered city bus example in Lafayette, Indiana, in the U.S. discussing equivalent voltage sources. Finally, student pairs debate the suitability of hydrogen fuel cells versus lithium-ion batteries for city buses, considering economic, environmental, ethical, and technical factors.

As post-class homework and exam questions, students identify ideal voltage sources, draw I-V curves for ideal and real-world sources, and research the I-V curves of solar cells. There is also a series of problems requiring students to analyze the impact of lithium mining on local communities, particularly indigenous nations, through a video about lithium mining near the Oregon-Nevada border in the U.S.

E. Lithium sourcing

This module addresses power and sustainability with lithium-ion batteries and is related to the topic of power and voltage sources, focusing on batteries as portable and modular real-world voltage sources. Students explore issues associated

with lithium mining and learn to balance technical specifications with ethical considerations while examining the tradeoffs of lithium mining and the impact of battery production on the environment and society.

As a pre-class activity, students answer a series of questions about power, comparing and contrasting electrical power and societal power. Then they investigate materials commonly used in batteries, such as lead, nickel, and lithium, and identify regulations associated with those materials.

During class, the instructor reviews the pre-class activity, highlighting assumptions like constant voltage and infinite lifetime, and discusses their relevance to real-world applications. The instructor describes materials used for batteries such as nickel, lead, and lithium, focusing on their regulatory concerns, and discusses lithium-ion batteries in modern electronics and their role in sustainability. The instructor then overviews lithium mining, including demand, projected supply, and historical production shifts. Next, the instructor describes social issues related to lithium mining, presents recent news and regulatory requirements, and discusses environmental, public health, and economic impacts, especially in the McDermitt Caldera region in Oregon and Nevada in the U.S. In pairs, students select an article to read about the impacts of lithium mining, discuss the article, and reflect on engineers’ social responsibilities.

As homework and exam questions, students investigate alternatives to lithium-ion batteries and reflect on their potential impacts on their future career. They analyze battery replacements, examine the social need for reuse and recycling, and explore methods to meet battery demand sustainably.

F. Power prioritization in hospitals

This module focuses on engineering design and sociotechnical ethics related to power sources in hospitals. It covers equivalent circuits, the current divider, and power calculations, plus social issues like prioritizing power based on criticality. The aim of the module is to educate students on ensuring reliable power in healthcare settings while considering ethical implications, including load shedding, power redundancy, and prioritizing essential services during outages.

The pre-class activity involves listening to a podcast about electrical receptacles in hospitals and answering related questions to understand essential electrical branches and “red outlets” in hospitals. Students also classify several hospital wards (intensive care unit, operating rooms, obstetrics, and physiotherapy rooms) as essential or non-essential, describe their reasoning, and calculate currents in series and parallel resistors for a given circuit.

During class, the instructor explains the criticality of reliable power in hospitals and the role of electrical engineers, then reviews the pre-class activity. The instructor discusses causes and effects of power outages, introduces power reliability issues in regions with unstable supplies, and presents concepts of redundancy and load shedding. Then, in groups, students defend a specific hospital ward’s need for power and decide which branch(es) to load shed during a simulated outage. Finally, the instructor facilitates a class-wide discussion on load shedding decisions and presents key takeaways.

Post-class homework and exam questions require students to justify their group's in-class decision about which hospital branch to load shed and calculate the resulting power distribution. Exam questions reinforce the technical and social aspects of power system design in hospitals, applying circuit analysis and ethical reasoning to real-world scenarios. An optional extra credit assignment challenges students to propose more complex load shedding strategies and promotes deeper exploration of power system design.

G. CO₂ emission in power generation

This module addresses social and environmental concerns of global CO₂ emissions from power generation and covers topics from circuits of complex power, the power triangle, and power factor correction. Key social issues include climate change challenges due to CO₂ emissions, the role of electrical engineers in mitigation, and strategies for reducing emissions through energy efficiency and power factor correction.

Before class, students watch a video asking "who is responsible for climate change and who needs to fix it?" and they answer related multiple-choice questions. This activity provides a foundation for understanding global CO₂ emissions, their magnitude, and engineers' shared responsibility for addressing climate change.

During class, the instructor introduces CO₂ emissions from power generation, emphasizing the energy sector's high contribution and the role of electrical engineers in improving efficiency and reducing emissions. In-class activities include identifying the top ten CO₂ emitting countries, discussing strategies to reduce emissions, and examining real-life engineering success stories. The instructor then reviews principles of complex power, explaining the power triangle, power factor, and power factor correction, and presents examples to show the impact of adding a capacitor for power factor improvement and the resulting CO₂ emission reductions. Students then discuss the economic feasibility and diminishing returns of power factor correction at higher levels.

This module includes nine possible homework and exam questions to help students apply theoretical concepts to practical scenarios. One problem asks students to reflect on the issues caused by CO₂ emissions and the role of electrical engineers in addressing them. Four short-answer problems require students to define types of complex power in an AC circuit, describe the effects of power factor correction, and address practical power factor correction issues in large industrial settings. The remaining problems involve calculating different types of power in AC circuits and designing for power factor improvement, considering its impact on energy efficiency and CO₂ emissions.

III. SUMMARY

With a cohort of seven graduate students, we have developed several modules for use in the Introduction to Circuits class. The modules connect typical technical circuits topics such as power and energy to social issues such as energy burden or sustainable development. The modules follow guidelines for effective integration of the social and technical and principles of backward course design.

To date, we have two proven modules and seven emerging ones, and which we described in this paper. Future work will involve piloting and refining some of the modules and launching them in Introduction to Circuits courses. We will collect data, including interviews of instructors and students, student surveys, and authentic student work, to assess the impact of the modules. We then plan to make the tested modules available more widely for instructors around the world to use in their Introduction to Circuits classes.

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TABLE I. TOPIC AND LEARNING OBJECTIVES FOR BOTH THE TECHNICAL AND SOCIAL CONTENT OF THE SEVEN EMERGING MODULES.

Technical topic and technical learning objectives	Social issue and social learning objectives
<p>Energy Efficiency <i>Power and energy</i></p> <ul style="list-style-type: none"> • Compute the energy consumption of a basic circuit • Compute and calculate the power absorbed or delivered by circuit elements 	<p><i>Energy insecurity, efficiency, LED vs lightbulb</i></p> <ul style="list-style-type: none"> • Recognize which of the 17 SDGs is addressed by reducing the power absorbed by an electrical circuit element • Explain the importance of using energy efficiency as a design consideration • Identify possible strategies engineers could use to target energy efficiency practices
<p>Energy Burden <i>Power and energy</i></p> <ul style="list-style-type: none"> • Compute the relationship between power and energy consumed by a circuit element over a given duration • Describe the meaning of efficiency 	<p><i>Sustainable development goals, efficiency, LED vs lightbulb</i></p> <ul style="list-style-type: none"> • Calculate the monthly electricity bill of a household given power ratings of appliances, average daily use, electricity rate • Compute the relationship between household income, energy costs, and energy burden • Describe the ill effects of high household energy burden • Prepare a case for replacing an appliance with one of greater efficiency by comparing monthly savings costs and computing payback period • Compare weatherization and time-of-use pricing as methods consumers can take to reduce energy consumption • Describe measures that policymakers can take to reduce household energy burden
<p>Energy priority <i>Open and short circuits, switches</i></p> <ul style="list-style-type: none"> • Explain open and short circuits and their relationship to switches • Identify open circuits and short circuits and correlate them to power outages 	<p><i>Geographic variation in energy access and stability, determining priority</i></p> <ul style="list-style-type: none"> • Critically analyze planned or unplanned outages and how the impact communities (e.g., those with low resources, disabilities, or dependencies on medical devices) • Design a circuit to critically distribute power when planned or unplanned outages happen
<p>Real-world voltage sources <i>Ideal voltage sources, sources in series</i></p> <ul style="list-style-type: none"> • Apply Ohm's law to calculate resistance, current, and voltage • Identify the characteristics of an ideal voltage source and an ideal current source and draw their I-V curves • Calculate the number of cells or batteries needed to power a resistive load 	<p><i>Hydrogen fuel cells, lithium-ion batteries, applications</i></p> <ul style="list-style-type: none"> • Identify one advantage and one disadvantage of lithium batteries • Identify one advantage and one disadvantage of hydrogen fuel cells • Identify the methods of producing hydrogen for fuel cells • Argue whether lithium-ion batteries or hydrogen fuel cells are more appropriate for a given design prompt
<p>Lithium sourcing <i>Batteries and voltage sources</i></p> <ul style="list-style-type: none"> • Define and discuss voltage and power • Explain the relationship between voltage, current, and power and write the associated equations • Compare and contrast voltage sources and their applications 	<p><i>Environmental and social impacts of lithium mining</i></p> <ul style="list-style-type: none"> • Explain circumstances for the extraction of metals and materials for voltage source production • Describe environmental and social impacts of lithium mining
<p>Power prioritization in hospitals <i>Series and parallel circuits, open and short circuits, power</i></p> <ul style="list-style-type: none"> • Analyze the current, voltage, and power in a circuit with multiple branches • Identify whether a resistor is in series or parallel with another resistor • Solve for currents in parallel branches • Calculate the power drawn from a source and dissipated in each resistor • Use switches to open and close branches to reduce the total power dissipated in a circuit 	<p><i>Red outlets in medical settings, prioritizing power</i></p> <ul style="list-style-type: none"> • Describe the engineering and ethical decisions that must be made to prioritize power to different healthcare usages • Defend an assigned perspective in an ethical decision and present the tradeoffs with evidence to peers • Weigh the competing factors and make and explain the rationale in a decision of what to prioritize
<p>CO₂ emission in power generation <i>Complex power, power factor correction</i></p> <ul style="list-style-type: none"> • Calculate P, Q, and S of an element from the rms voltage or current and the impedance of the element • Calculate the power factor of a circuit 	<p><i>Geographic variation in CO₂ emission, Climate change</i></p> <ul style="list-style-type: none"> • Describe issues caused by CO₂ emissions and discuss how electrical engineers can contribute to addressing these challenges • Apply power factor correction to reduce the amount of total generated power, and amount of CO₂ emitted into the atmosphere