



Practice Paper

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PILOTING A SOCIOTECHNICAL MODULE ABOUT ELECTRIC VEHICLE BATTERIES IN A SMALL CIRCUITS COURSE (PRACTICE PAPER)

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ABSTRACT

Motivation to include sociotechnical content in engineering courses comes from students, the workplace, and accreditation bodies. However, incorporating explorations of engineering's social impacts is challenging for most engineering professors who have been educated with a deep technical focus. In this work, we offer one option for addressing social implications in a required course for many engineering students (i.e., Introduction to Circuits). We developed a one-hour class module focused on electric vehicle (EV) batteries and circular economies that can be integrated into the basic Circuits course. The module includes pre-class, in-class, and post-class materials contained in a comprehensive teaching guide. We piloted the module with a few students and then deployed it in a small undergraduate-focused institution. In this paper, we outline the module development process, which leverages the principles of backward design, and present examples of the module materials. Students did well on the related homework problems and were enthusiastic about the discussions, calculations, and focus on the circular economy. Interviews revealed that students valued the connection of technical and social aspects and enhanced their interest in electrical engineering. We hope that this module will help engineering instructors interested in teaching about social implications in their own Circuits courses.

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1 INTRODUCTION

Motivation to include sociotechnical content in engineering courses comes from students, the workplace, and accreditation bodies. Many undergraduate students enter engineering wanting to help people through their profession (Bairaktarova and Pilotte, 2020; National Academy of Engineering, 2008). They want to see how their engineering knowledge can make a difference in people's lives. Real problems provide this opportunity - they are multidimensional and interdisciplinary, and they encompass complex sociotechnical issues (Baillie, Pawley, and Riley, 2012; Leydens and Lucena, 2017; Riley, 2020).

To prepare graduates for the workforce, instructors must help students learn about technical and social dimensions of engineering. Engineering accreditation criteria (e.g., ABET, n.d.; the European Network for Accreditation of Engineering Education, n.d.) emphasize the importance of such sociotechnical knowledge by expecting engineering undergraduate programs to address ethical, global, cultural, social, environmental, and economic considerations in student outcomes.

However, many engineering instructors, educated with in-depth technical knowledge, are not sure how to incorporate explorations of technology's social impacts. Instructors may also feel that they do not have time to develop instructional material that connects the social and the technical. As a result, many students learn core engineering concepts with a focus on calculations and modelling but no critical evaluation of their major's impact on sociotechnical areas such as public welfare, ethics, climate change, and policy (Bielefeldt, 2018; Børsen et al., 2021; Jesiek et al., 2019; Williams and Trevelyan, 2013).

In our current research project, we offer one approach for addressing social implications in a required foundational course for engineering students. We aim to help engineering instructors to provide sociotechnical content for their students by making it as easy as possible. We are developing short, one-hour modules for use in the Introduction to Electric Circuits course that connect social and technical considerations. The Circuits course is typically the first course for students studying electrical engineering (EE) and is a common course for students in other disciplines of engineering. Thus, this course reaches many students. It is a course that students often find very abstract and struggle to find the relevance of (Bell and Horowitz, 2018). Our modules are designed to be used in this foundational course where we hope they will help students see the relevance of the technical content and instructors be empowered to conduct discussions of the sociotechnical nature of the course content (Lord, Przestrzelski, and Reddy, 2019; Finelli and Lord, 2023; Lord and Finelli 2023).

In this paper, we report on the development and implementation of a one class period (about one hour) module focused on electric vehicle (EV) batteries and circular economies that includes pre-class, in-class, and post-class materials contained in a comprehensive teaching guide. In May 2023, we piloted the module with a small group of students and then deployed this module in a small undergraduate-focused institution with twenty students. After the session, we conducted interviews with two student participants. In this paper, we present examples of the module materials and student feedback. We hope that this module will help engineering instructors interested in integrating social implications in their own Circuits courses.

2 DEVELOPMENT OF MODULE

The goal of this module, “Electric Vehicle Batteries and the Circular Economy” is to introduce students to issues related to recycling the rapidly growing number of electric vehicles (EVs) reaching end-of-life. This topic serves as a case study for applying principles of a circular economy. For the instructor, we supply the learning objectives; assignments for before, during, and after class; the in-class slides; and an accompanying instructor’s guide to the slides. Instructors may choose any combination of problems and/or slides and can choose when in the semester to insert the content.

The module was developed by a graduate student in EE along with two EE professors with decades of experience teaching the Introduction to Circuits course (preliminarily described previously Judge, Lord, and Finelli, 2022). We used the principles of backward design (Wiggins and McTighe, 2005) and constructive alignment (Biggs, 1996) to connect learning objectives with activities and assessments. We also followed guidelines developed by Gelles and Lord (2021) for integrating sociotechnical content into engineering courses.

1. Identify a salient course topic that has broader social and environmental implications.
2. Identify, add, or update existing course learning objectives and/or ABET student outcome that this sociotechnical course topic aligns with.
3. Create learning objectives for specific sociotechnical modules.
4. Create modules by designing activities for homework before and/or after class session(s) as well as class session(s) that integrate technical content and calculations students are familiar with and social and environmental context.
5. Include low stakes assessment for module (e.g., homework) and consider including sociotechnical questions on exams.
6. Conduct formative assessment and/or engineering education research on sociotechnical modules to get student input and improve module offerings in the future.
7. Refine modules and identify possible sociotechnical collaborators for the next course offering.

To accomplish Step 1, we began by relating the concept of voltage dividers to repurposing of electric vehicle (EV) batteries. The manufacturing and use of EVs has increased dramatically recently (Breiter et al., 2022; IEA, 2022). Many students are familiar with EVs; thus this topic is relevant to current undergraduate students’ lives and connects to EE. Once EV batteries have degraded to about 70% of their initial charge storage capability, they are no longer useful for EVs since they could leave a driver stranded. Recycling has many challenges (Kul, 2022; Morse, 2021). However, they may be very useful for other applications. (Ali, Khan and Pecht, 2021; Haram et al, 2021; Song et al., 2022). Thus, the repurposing of EV batteries is an excellent topic for introducing students to the circular economy. The circular economy is “a system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like

maintenance, reuse, refurbishment, remanufacture, recycling, and composting” (Ellen MacArthur Foundation, n.d.). In addition, because repurposing EV batteries likely involves changing a DC voltage, the topic can be connected to voltage dividers, a concept addressed in most circuits courses that can be used for both analysis and design. Voltage dividers are typically covered early in the Circuits course, and the EV module could be done any time after voltage dividers have been introduced. We acknowledge that voltage dividers are not the best way to provide a desired output from an EV battery and mention this to the students. However, we felt that it was important for them to see an application of something in the class that could be connected to a larger topic.

For Step 2, we identified a series of course learning objectives related to the EV module. The learning objectives include:

- Be able to write, derive, and apply the voltage-divider relationship for circuits containing two or more resistors.
- State when it is appropriate to use the voltage divider equation.
- Explain what a voltage divider is and why it is useful.
- Analyze batteries as DC electrical devices

Next, for Step 3, we identified specific learning objectives for the sociotechnical module. These module learning objectives include:

- Design a voltage divider for a DC source to illustrate repurposing EV battery packs
- Estimate energy available in end-of-life EV batteries and explain how they could be used for other purposes
- Describe societal risks introduced by recycling EV batteries that could be alleviated by applying circular economy principles

Steps 4 and 5 involved developing materials which will be summarized in the next section. This paper is part of Step 6 and we are in the process of Step 7 as we refine the module.

3 SAMPLE MATERIALS

3.1 Pre-class Problems

Before the class session with the integrated module, instructors could ask students to complete some pre-class activities. One possible pre-class activity is that students could listen to one or more podcasts that introduce concepts related to EV Batteries and the Circular Economy (e.g., Loveless and Sanderson, 2022; Whalen, 2020) and answer multiple choice questions. Another possible activity is a numerical calculation (Fig. 1, note that estimates of numbers of EVs may need to be updated as this is a rapidly changing field) which sets the stage for the need for EV battery repurposing. Instructors also have the option of not assigning pre-class activities and doing the initial calculations as an in-class activity.

End-of-life battery capacity and the circular economy: In the year 2021, there were about 16.5 million electric cars on the road, and the numbers continue to increase. Annual sales of electric cars are predicted to reach approximately 30 million in the year 2030. Assume that each EV battery pack has an initial 500-volt charge at time of sale and that approximately 70% of EV battery packs from 2021 will reach their end of life by the year 2030 (still having 75% of their initial capacity). Then, answer the following questions:

- a. When the EVs from 2021 reach their end of life, how many total volts will remain on the battery packs?
- b. What percentage of future battery demand (in Volts) could be supplied using repurposed batteries from 2021?
- c. What does this imply about the feasibility of using repurposed EV batteries?

Note: The initial charge on EV batteries currently ranges from 300 – 900V, which connects to either a 400 or 800 V system. There is an industry movement to standardize the 800V system level design for faster charging.

Fig 1. Sample pre-class assignment

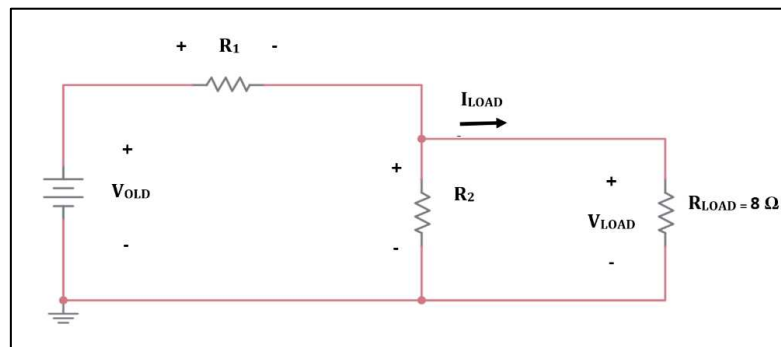
3.2 In-class Presentation

To support instructors using the EV module, we developed a slide presentation and accompanying script with suggested timings. The presentation includes descriptions of EVs and EV batteries, an overview of the circular economy, prompts for student discussions, and example voltage divider problems in the context of EV battery repurposing.

The instructor presentation begins by describing that, when they reach their end of life, the growing number of EV batteries are no longer suitable for use in EVs. The numerical example (done either as a pre-class activity or inserted in class at this point) illustrates that recycling can only meet about 30% of the demand for future EV batteries and that this complex problem requires engineers. The instructor then outlines assumptions that were part of the calculations and introduces benefits and challenges of recycling EV batteries, leading to a discussion of the circular economy and its implications for engineering design. Next, students are encouraged to think of applications of the circular economy for EE and then to focus on EV batteries. The instructor illustrates that an EV battery with an initial range of 150 miles has a reduced range of only 105 miles, potentially insufficient for the owner, when its capacity is diminished to 70%. Then, as a fun way to see this idea in action students check the health of their phone batteries.

Next, the instructor describes what the circular economy might look like throughout the life cycle of the battery. The instructor highlights some industry areas where repurposed EV batteries could be used, including microgrids, and then presents students with the challenge of powering a microgrid that requires a specific voltage (e.g., 350 Volts) with an EV battery having 493 Volts. Students are guided to use the voltage divider, and they design a circuit to provide the appropriate scaling. The instructor confirms their answers and discusses how the voltage divider is not the ideal circuit for this giving them a glimpse of more complex circuits. The instructor then transitions into preparing for the homework and summarizing main takeaways from the module.

1. (a) Provide an example of a challenge or solution for each of the following sociotechnical factors in the manufacturing and repurposing of EV batteries: Technical, Environmental, Health and safety, Economic. (b) Please provide a few sentence description of **one** of these.
2. In your own words, describe the purpose and benefits of a circular economy.
3. A repurposed battery (represented by V_{OLD} in the schematic diagram below) is used to power a mobile home. The load requires 240 V and 30 A to charge, and the load resistance (represented as R_{LOAD}) is included to draw current from the battery – this is a common rating in microgrid applications. In this problem, R_{LOAD} is $8\ \Omega$ and R_2 is $100k\Omega$.
 - a. Assuming that the repurposed battery is a 600 V pack at 76% capacity, enter the following values in the table below.
 - i. The effective voltage of the entire second-life battery pack, V_{OLD} . (You may assume that all the current can be supplied by the battery)
 - ii. The value of R_1 required to set the output voltage and current to 240 V & 30 A.
 - iii. The total power supplied by the repurposed EV battery to the load.
 - b. Repeat the calculations for (i) – (iii) if the battery degrades over 2 years to 65%.
 - c. Describe what concerns you might have about your results.



Battery Capacity	$V_{OLD}(V)$	$R_1(\Omega)$	Power Supplied to Load (W)
76%			
65%			

Fig. 2 Example problems for after the module

3.3 Post-class Problems

We provide several options for post-class activities (Fig. 2, note that these problems could be used for homework and/or exams). We also provide a list of related references on EV manufacturing and the circular economy.

4 STUDENT RESPONSES

In May 2023, the graduate student who developed the EV module presented it in an “integrated approach to EE” course taught by a member of the research team. The course is for second year students and is a broad introduction to EE, including many circuits topics. The day before the module was presented in class, we piloted it with a small group of volunteer students who had taken the course the previous year. Overall, the volunteers found the module interesting and informative, and their feedback was incorporated into the module before it was presented to a class of 20 students on the following day.

4.1 Pre-class Problems

For the Spring 2023 offering, we did not do the pre-class problems. Rather, we incorporated the activity (Fig. 1) into the beginning of the class period. Students successfully completed the calculations for the activity during class.

As an extra credit assignment, students in the class were asked to listen to the two podcasts and explain which one they thought would be more beneficial as a future pre-class assignment. Of the 20 students, ten did not complete the extra credit assignment, six students preferred the longer podcast, which was about 40 minutes, (Loveless and Sanderson, 2022) for its comprehensive technical details, three preferred the shorter podcast, which was about 18 min, (Whalen, 2020) for its clear organization and relatable host, and one did not make a recommendation. Instructors can decide which, if either, is more appropriate for their class.

4.2 In-class Feedback

The student volunteers who participated in the first offering in Spring 2023 were very enthusiastic about the module and the topic. In fact, one of the students was so inspired that she proposed the topic of repurposing EV batteries for her engineering senior design course for Fall 2023-Spring 2024 and is currently working on this with an interdisciplinary team and considering starting her own business.

Students who participated in the class module recorded their impressions about it at the end of the session by listing one thing they liked about the module and one suggestion for improvement. Students liked the discussions, the calculations, consideration of the circular economy as a current issue, and thought the presenter did a good job. For example,

“Enjoyed calculations and real applications so we could see it wasn't as theoretical.”

“The discussions and activities went really well.”

Students also provided several suggestions for improving the module including considering the pacing as *“some points went too fast, but others took too long.”* Several students suggested topics to add such as more detail on manufacturing process for batteries, overview of how EV batteries work, where parts go, different types of batteries, and changes to infrastructure needed.

4.3 Homework Problems

Students completed the three assigned homework problems in cooperative learning groups of four (Lord, 2001) as part of the final assignment of the semester, and overall they did well on the problems. Of the five groups, three got full credit for

Problem 1, the fourth group earned 1.75/2 (88%) for not substantiating statements about costs, and the fifth group earned 2.25/2 for an outstanding job. For Problem 2, four groups earned full credit and one earned 0.75/1 for a grammatical error and not providing a citation for “biodiversity loss” as an integral part of the circular economy. For Problem 3, three groups received full credit, one earned 2.5/3 (83%) and one got 2.25/3 (75%). Common student errors included insufficiently explaining why numbers were chosen, using wrong numbers, and calculating power supplied by the battery rather than to the load. Students were encouraged to use Multisim simulation to check their work.

4.4 Interviews

Students responded enthusiastically to the implementation of EV module. Two students from the class, both of whom were female Integrated Engineering majors, participated in semi-structured interviews after the module. One was pursuing a concentration in biomedical engineering and the other in sustainability. Both students described the module as interesting, relevant, and helpful.

“I think if more people knew about [topics like this EV module] and it was brought to the attention of more people, especially like our generation of engineers, it would be really helpful towards the future.”

“... [the EV module] definitely made me consider going into something that does more with like sustainability and stuff like that.”

One student expressed an honest opinion about not being excited about EE at the beginning of the semester, stating that this module helped improve that outlook.

“... I came in hating electrical engineering, like it was just not for me. So I think like actually doing the voltage divider and using that for like sustainability purposes and the circular economy was really cool to like actually be like, okay, the stuff we're learning is like being used for something I liked that part of it.”

One student emphasized the importance of this topic to them personally.

“... we are a part of the issue if we don't decide to fix it.”

5.SUMMARY AND FUTURE WORK

We successfully designed and implemented a sociotechnical module about EV batteries and the circular economy in a small undergraduate engineering course. The module ties the technical topic of voltage dividers, typically included in an Introduction to Circuits course, to the circular economy using the idea of repurposing EV batteries. Students responded enthusiastically and liked seeing the connection between the social and technical concepts.

Next, we aim to scale up our implementation by integrating the module into a significantly taught by a member of the research team a different institution. We will also conduct surveys, interviews, and focus groups to gauge student feedback on the module and evaluate students' homework solutions to assess their technical proficiency. Then we intend to collaborate with engineering educators to introduce this module into circuits courses at universities beyond our research team's institutions.

We are currently partnering with eight graduate students from across the USA to develop more sociotechnical modules for the Introduction to Circuits class. Once these are successfully implemented in our own small and large courses, we will share them with other educators, thus impacting students at many universities.

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