# Sustainability-focused Digital Case Studies: Enhancing Engineering Education

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## Title

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**Abstract**

Educators, students, funders and federal agencies are increasingly involved with conversations surrounding sustainability and environmental justice in engineering, and recognize the need for this to be a key feature in curricula. At the same time, active learning and notions of learner agency, informed by their lived experiences, are shaping classroom pedagogy. At our university, we conducted a pilot study in a graduate level engineering course: *Fundamentals of Renewable Energy Processes and Electrochemical Storage*, which involved introducing collaborative and individual case-based writing as the final assignment instead of a traditional term-paper. We analyzed the deliverables and conducted interviews with a sample of the learners from the class to explore how the shift impacted student learning on sustainability. More specifically, we asked:

1. Can authoring an open source, case-based assignment (instead of a traditional term paper) capture self identity and lived experiences, create a stronger sense of agency in learners, and increase "stickiness" of the knowledge?
2. Can working collaboratively with other learners personalize the knowledge absorption process and build team based skills?
3. Does access to open educational resources facilitate integration of sustainability or social justice concepts into the engineering curriculum?

This research discovered that student motivation is significantly improved through projects that extend beyond the academic environment, particularly those that align with their interests in sustainability goals. Moreover, capabilities on the Gala platform such as concomitant co-authoring and co-editing, and integrating multimedia communication tools, allow students to share their experiences and motivations in a more relatable and accessible format Notably, the study found the Gala module to be effective in driving student motivation because of the reach of modules which could extend well beyond their classroom, to future cohorts of the class, or other classes. Findings include feedback for subsequent runs of this intervention in the same classroom, as well as a call to engineering educators wishing to integrate student experiences and sustainability in their classrooms to explore the capabilities of open-source case-authorship tools.



Key words: Engineering education, sustainability, open-source educational resources


**Introduction**

Indicative of the critical role engineering plays in the design of just and climate-change resilient technologies, curricular design both within the U.S. and internationally (Europe, Australia, South Africa, and Asia) is shifting its focus to sustainability [1,2]. To best prepare the next generation of problem solvers through education for sustainable development (ESD), the United Nations Educational, Scientific and Cultural Organization (UNESCO) defined a framework of core sustainability competencies including

concepts such as: systems thinking, anticipation of the future, balancing trade offs, collaboration, critical thinking, self-awareness, and problem solving [3].

To this end, the first Engineering Education in Sustainable Development Conference was held in 2002 [2], and since then, a variety of pedagogical strategies have been proposed. These approaches include problem-based learning [4] and project-based learning [5], which are described as student-oriented, collaborative, self-directed, and focused on real-world challenges. Service-learning (SL) is another technique used in engineering curricula, which engages students in community service to nurture a sense of social responsibility [6,7]. There are common goals among these strategies which align with UNESCO's competencies, including understanding stakeholder needs, developing collaborative skills, and solving complex problems. Many of these works present effective techniques to augment the *learning process*, whereas our study places emphasis on methods to improve students' ability to *synthesize and communicate* their learned knowledge to a broad audience.

This study explores the potential of Gala – a new, open-source, case-based learning platform – to help students meaningfully package and present their learnings from project, problem, and service-based learning. Gala's digital, open-access structure and focus on sustainability education attracts creators with diverse expertise, intent, and backgrounds [8,9]. The variety of creator's interests is reflected in **Figure 1,** which highlights the spread of case studies across the globe. The platform also invites learners to engage with the material through conversation threads, providing valuable feedback for the author(s). This unique tool encourages student agency and creativity in the classroom by inviting them to weave their experiences, understandings of sustainability issues, and acquired knowledge into a story. As described in an article online, the platform (accessible here: https://www.learngala.com/) is continuously growing with support from multiple NSF grants [10].

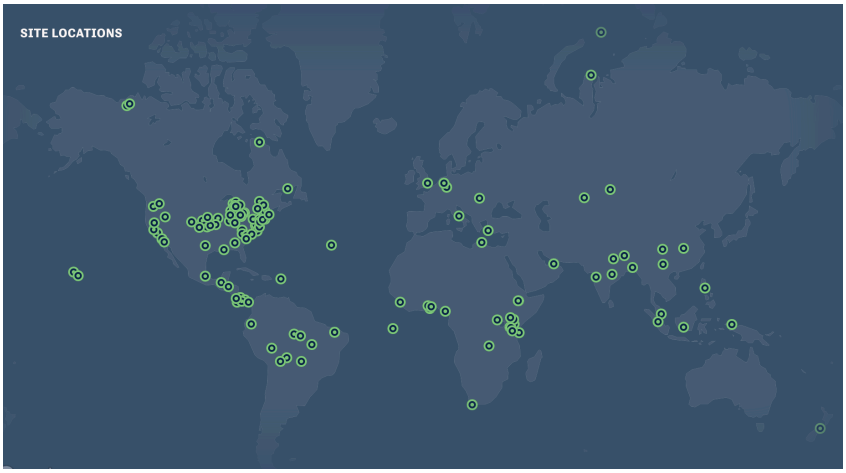


**Figure 1.** Locations of case studies authored on Gala. (https://www.learngala.com/)

This study was piloted in a graduate-level engineering class at the university called *Fundamentals of Renewable Energy Processes and Electrochemical Storage*. The final project is traditionally a term paper which frames a renewable energy technology such as thermal energy storage, perovskite solar cells, or fast-charging Li-ion batteries. Students are asked to provide context on alternative solutions along with a

technical description of the technology and future needs/opportunities. For the purpose of this study, students created their final project on the Gala platform rather than a term paper.

While there is some literature that supports the introduction of concepts of sustainability in engineering classrooms using design thinking approaches [11], sustainability literacy tests [12], capstone projects [13,14] and using case studies, few articles have discussed the impact of students writing open-educational resources (OER), namely scientific cases. Gala houses digital educational material on sustainability and is developed on infrastructure that organically sees user/creator groups from across the globe. This OER is an interactive database with cases having the capability to be iterated by case-writers and interacted with by its users. These cases are mostly worked on collaboratively by students, educators, researchers, administrators, for communicating sustainability problems, observations and innovations. The OER community can adapt to shifts in the educational environment, with literature pointing to a need for conversations on social and environmental justice in engineering classrooms [15].

The platform supports the use of multimedia such as videos, images, and embedded links, which is not typically possible in a written paper. After case-studies were submitted, the authors investigated students' experience authoring these open educational resources rather than a traditional paper. The open-access nature of the case study instills action-orientation within students to catalyze academic growth and fosters a sense of responsibility towards the community and the environment. This instructional method, driven by open learning, shows promise to expand the boundaries of engineering education by enabling translation of sustainability concepts and lived experiences across geographies and generations.

**Study Approach**

This work focuses on the difference between authoring a digital case study on an open-source, educational platform and writing a traditional term paper with emphasis on the students' experience synthesizing and communicating sustainability concepts. The renewable energy course blended big-picture motivation for studying sustainable technologies with theoretical principles in topics such as thermodynamics or quantum and solid-state physics.

Students first built a scientific foundation and gained inspiration for Gala case studies through lectures and homework assignments. The founder of Gala also joined the class once early in the semester as a guest speaker to introduce the platform. Then, halfway through the semester, Gala case study examples were supplied, and students completed the project at their convenience before the end of the course. A purposefully broad rubric (see **Appendix A**) was provided to determine how the format of the case-study versus a term paper might inherently influence students' approach to presenting information focused on sustainable technology. The authors then collected data on the student experience as discussed in the Methods section.

The online Gala case-studies began with an introduction page with learning objectives for readers. Further information regarding their chosen technology was broken into chapters.

Overall, the open-access nature of the case study instills action-orientation within students to catalyze academic growth while fostering a sense of responsibility towards the community and the environment. This instructional method, driven by open learning, shows promise to expand the boundaries of

engineering education by enabling translation of sustainability concepts and lived experiences across geographies and generations.

**Methods**

For dealing with human subjects, information pertaining to the clearance we received from the Institutional Review Board is: *Study ID: HUM00112459 | Study Title: Michigan Sustainability Case Assessments | PI: Rebecca Hardin*

The process used to gauge student learning is summarized in **Figure 2.** The Gala case studies were evaluated by the instructor through the rubric in **Appendix A**. Additionally, a self-reflection form (questions in **Appendix B**) was written and distributed to the students through a Google form. Students self-evaluated their competencies regarding sustainability problem framing, creativity, collaboration, environmental/social justice awareness along with their suggestions to improve the case-writing experience in following courses. From the pool of respondents, several students volunteered for an interview to further expand on their experience writing the case-study.

Interviews (questions in **Appendix C**) were conducted by two members of the research team who are doctoral students studying this learning intervention. Each interview lasted 45-60 minutes and was conducted with six evaluation respondents and the course instructor for a total of seven interviews. Qualitative content analysis (QCA) [17] was applied to analyze the data, in which data from students' self-evaluations and interviews was coded into themes, and the frequency of responses within each theme was recorded. These themes included broader impacts of the digital case study format, exposure to sustainability in engineering education, students' lived experiences, and pedagogical methods.

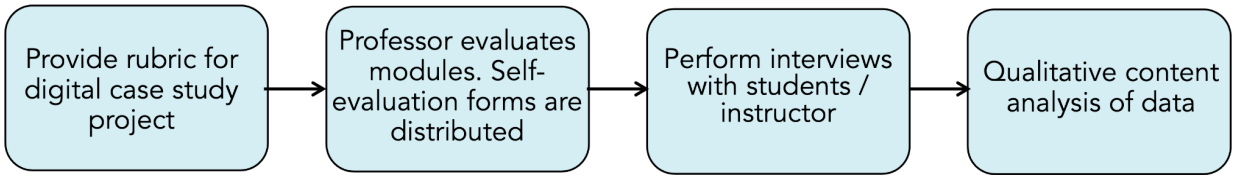


**Figure 2.** Flowchart depicting the study approach.

**Results and Discussion**

This section reports the qualitative analysis of the surveys and interviews. The first survey captured students' self-reported competencies in collaboration, problem framing, and creativity before and after writing the case study. Both the before and after responses were collected after the course was complete, and descriptions of each skill were provided in the survey as follows: **Collaboration**:"Working together with classmates who have common interests or a common goal." **Problem framing**: "Ability to (1) Understand the problem's scope and causes (2) Gather Information, understand project details and constraints (3) Evaluate stakeholder needs and expectations (4) Create a clear, concise, problem statement." **Creativity***:* "Using different modes of communication, through multimedia and narrative, to convey scientific ideas effectively to broader audiences." After ranking themselves, students could provide more detail regarding their response through a short-answer response. The survey results are displayed in **Figure 3**.

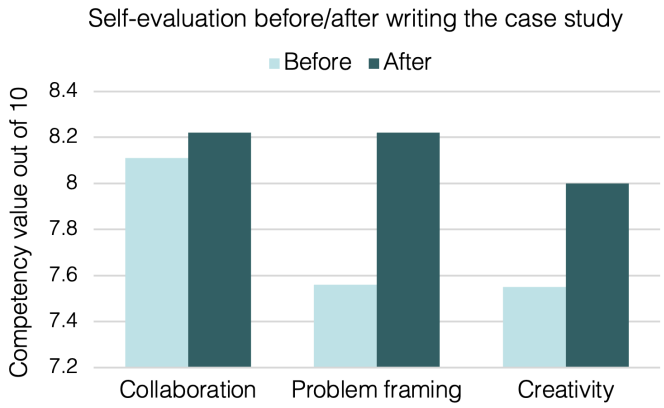


**Figure 3.** Students' self-evaluation results before and after writing an open-source case study focused on sustainability technology (values averaged from nine respondents).

Survey results show that writing a Gala case study did not significantly impact students' collaboration skills but positively influenced problem-framing and creativity. Students' short-answer responses explain that group projects are pervasive in undergraduate / graduate engineering curricula. Thus, the graduate students who participated in the study were already accustomed to group-work.

On the other hand, problem framing skills improved by 8% on average. One student stated that the Gala platform helped reduce project scope creep. The authors were able to present information clearly within the original scope and include embedded resources. The additional images, articles, and videos allow learners to explore beyond the intended scope if they choose, while preventing the module from becoming too broad. This exercise in differentiating necessary from supplementary information contributed to students' problem-framing development.

Similarly, students felt their creativity improved by an average of 6%. Responses state that in previous engineering classes, students had no prior opportunities to "teach a topic in creative ways." By keeping a broader audience in mind, students were "challenged to convey scientific information in a different, more engaging way." Aiming to engage a reader beyond an instructor or peer encouraged them to, "change [their] writing style and employ more media, such as YouTube videos, in the project." Furthermore, freedom to organize the module outside the framework of a traditional paper helped students "understand a better chronology to explain sustainability issues." Overall, The knowledge that the module "could be beneficial to someone in the future" motivated students to write more freely and create a story.

In addition to the self-evaluation form, interviews were conducted to better capture students' case-writing experience and learn about their prior exposure to sustainability. **Table 1** displays interview quotes sorted into themes and presented alongside corresponding takeaways which reflect the self-evaluation form responses. Students' names were changed for anonymity.

**Table 1.** Interview themes, quotes, and takeaways.

| Theme | Quotes | Takeaway |
|---|---|---|
| Open-source module vs. traditional term paper | "It's easy to shut everything else out and focus on publishing papers, but I think we need to challenge ourselves to do more than that…too much of the scientific community focuses on narrow topics…not thinking about broader impact." [Patrick] | The open-source, digital case format supports students' desire to contribute to society, enabling them to make a lasting impact and share their gained knowledge with a broad audience. |
| | "I recognize that it could reach a larger audience than just a professor who might read it once…I like the outreach impact it could have, improved stakeholder engagement, more community involvement in engineering solutions." [Anna] | |
| | "People from other classes can use it as educational material, and not have your paper sit somewhere." [Brittney] | |
| | "Focus more on societal impacts…it's refreshing to not focus on the technical aspects 100% of the time." [Herb] | |
| | "I never want to write a paper again…[it was] more motivating knowing the work had future meaning" [Taylor] | |
| | "I noticed in academia, papers are a very old way of absorbing information, and now we have tech that allows us to absorb info in different ways…tech has outpaced the way of learning" [Oliver] | Gala enhances the learner AND creator experience by enabling story-telling. The format caters to a wider audience by enabling presentation of material through different media (e.g. videos, 3D CAD models) |
| | "I enjoyed trying to find other sources to put into the Gala module to make it more enjoyable for people to read." [Anna] | |
| | "It allows you to combine text, images, videos, different media. It is a good way to connect technological issues and communicate them to the broader public." [Patrick] | |
| Exposure to sustainability in engineering education | "My school installed a wind turbine…my first tech based connection, got me inspired to focus my studies in that direction." [Taylor] | Exposure to sustainable technology in the field can be formative in a student's education and pursuits |
| | "I took two sustainable technology classes in undergrad…one was in electrical engineering, one was a special topic in mechanical." [Herb] | |
| | "In undergrad we had a science elective…gave me more of an understanding of how sustainability is important." [Oliver] | |
| | "We were a small school, we didn't have resources like here. The range of choices was limited." [Brittney] | |
| | "My grad school course…did a field trip to a wind farm…remembered that for the rest of my life. That's missing. Guest lecturers, field trips…People are willing to learn but you need to show them why it's important." [Course Instructor] | |
| Lived experience | "My grandfather is an ecologist, it was very important to me to learn about and be in the environment." [Taylor] | Acknowledging students' lived experiences and prompting self-reflection through course design can benefit students by helping them understand their motivation and how they may be uniquely positioned to contribute to equitable, sustainable solutions |
| | "I grew up in Chicago, my family sought out opportunities to be in nature on vacations and weekend trips, like walking through the forest, hiking…I grew up wanting to protect that." [Herb] | |
| | "I liked playing with bugs and frogs as a kid…I just want to preserve the health of animals, plants, and humans, and I see solar energy as a way of doing that." [Oliver] | |
| | "...in some seasons like summer, if rain is very heavy, you sacrifice some smaller cities to protect larger capital cities...I was usually afraid, if the rain is too heavy my family would have to move…I experienced something that's not great and I want to learn more about what's going on." [Brittney] | |

Qualitative analysis of the surveys and interviews provide insight into the student learning process, pedagogical design in classrooms, and influences on students' sustainability motivations. Next, referring to **Table 1**, we explain the themes that emerged through our analysis to explain the influence of co-creation of the open resource case on student learning.

*Collaborative case creation is more motivating than a term paper.*
Collaborative case creation has been found to be a motivating and effective learning method in various studies [18]. Xiao [19] highlights the positive impact of collaborative case-based learning activities, with students expressing enthusiasm and offering suggestions for improvement. Jeong [20] emphasizes the importance of motivation in collaborative research, suggesting that it can significantly enhance research impact. More such studies collectively suggest that collaborative case creation is indeed more motivating than traditional term papers.Cases were written on the Gala platform using mixed media for broad audiences extending beyond the classroom and instructor. Students found meaning in creating an artifact that would potentially be read by an audience and had educational implications of their interests and work. Interviews demonstrated that the case study writing format supported student's implicit desire to contribute to society and sustainability (as evidenced in **Table 1**). The evaluation of a digital case study approach compared to a traditional term paper revealed insights about student engagement and learning motivations. The accessibility and broader audience application of a digital case study led to an enhanced sense of motivation among the students versus a traditional term paper.

*Gaps in curricular integration of sustainability-focused experiential learning.*
Based on quotes from the 'Exposure to Sustainability' theme in **Table 1,** sustainability courses were not integrated into prescribed undergraduate or graduate engineering curricula, and in some cases this may have been due to a lack of resources. Rather, students independently sought 'special topics' to support their interest in sustainability. This lack of emphasis on sustainability contrasts the descriptions of in-person exposure to sustainable technology which ultimately steered those individuals toward sustainable engineering careers. The instructor's sentiment that "people are willing to learn but you need to *show them* why it's important," echoes McCormick *et al.'s* work from 2015 [21]. They found that "participation in more experiential, enriching learning," improved the value students place on sustainable engineering and their feelings of self-efficacy [21]. To this end, Davidson *et al.* underscore the need for online learning platforms that can provide 'rich learning experiences' and networks for communication [22].

As a digital, open-access platform, few resources beyond internet access are required to integrate Gala into any engineering classroom. The creation of a vibrant story on the Gala platform can provide a richer learning experience and help the importance of students' work stick with them. Furthermore, generating a final product that can reach a broad audience gives students a greater sense of agency than a term paper. Students' sentiments that their work will impact future generations can build faith in themselves to move forward and create a sustainable future.

*Lived experiences of students influenced their sustainability values and meaning-making in class.*
Lived experience formed another crucial factor that often goes unrecognized in formal education [23]. The interviews revealed that minority and international students drew heavily on their personal experiences as motivational factors. Yet, these experiences were seldom incorporated into the formal curriculum in their prior experiences. Acknowledging the varying impact of sustainability and climate change on different demographic groups [24], the paper suggests incorporating self-reflection and future planning in the engineering curricula. The case-study format also presented an opportunity for students to consider the integration of a broader audience and have educational objectives. Students also found the

open-ended writing process beneficial in expanding their future career pathways to work in labs focusing on sustainability. Furthermore, the digital case study encouraged a sense of responsibility among students toward contributing to societal and environmental sustainability.

*Instructor reflections.*
The researchers conducted an interview with the course instructor (questions in **Appendix D**). From their perspective, the digital case study approach resulted in increased engagement and enjoyment during lecture sessions and grading assignments. Students were more responsive to discussions on broad sustainability aspects, thereby initiating an authentic educational discourse. The instructor's reflections also underlined the importance of experimenting with newer teaching methods for enhanced learning. The instructor's reflections described that future approaches should expand on the narrative case structure to incorporate mixed media and industry insights to bring about a more engaging and effective learning experience. Moreover, having an open space for sharing and learning from lived experiences would create a more inclusive and relatable educational environment. The digital case study compared to the traditional term paper has potential to integrate sustainability effectively into engineering education.

## Conclusions

To embrace sustainability in the future, it is necessary to shift not only to clean energy but towards a sustainable mindset – pedagogy is fundamental to achieve these transitions [25, 26, 27]. This work examines how students experience writing a sustainable-technology focused, open-source case study (on the Gala platform) compared to generating a term paper in a renewable energy course. The originality and promise of the Gala module toward enhancing students' engagement with sustainability in engineering education lies in the ability to iterate the content, reach a broad pool of both authors and learners, and foster collaboration. After publishing online, the case study remains accessible to all authors and viewers and simple to update, enabling the "living" module to keep up with constant changes and advancements in the environment, science, and culture. The open access to the learning platform can create sustainability-centered conversations in engineering curricula and facilitate exchange of ideas between academia, industry, and communities across the globe. Finally, the creative process is inherently collaborative [28]. At a time when communities are experiencing climate change in vastly different ways, understanding and learning from one another's lived experiences, it is paramount to create solutions collaboratively that truly address society's current needs and those of the next generation [29, 30].

The analysis of this study directs us to make these pedagogical suggestions:

1. Students' strong motivation to contribute to areas of sustainability can be circulated in classrooms by providing students with authorship avenues for diverse audiences. This motivation has been demonstrated in previous studies [31].
2. Using multimedia in case-writing can help students visualize and communicate their ideas effectively. This also allows students to engage in self-reflection, thereby broadening their understanding of career pathways [32].
3. Including specific guidelines on incorporating aspects of environmental and social sustainability in the case and explaining sustainability competencies to students could provide room for more detailed feedback and self-evaluation on those competencies

4. More formal avenues for self-reflection and discussions of students' experiences would also bring conversations on the disproportional impacts of sustainability challenges on different demographic groups into engineering education classrooms [33].

*Future Work:* In future studies, students might receive explicit instructions to include sustainability, economic, and environmental/social justice information in the module. This approach may use a scaffold of five key competencies for sustainability by UNESCO (Systems thinking, Futures Thinking, Values thinking, Strategic thinking, and Interpersonal Collaboration) [34] to evaluate how this structured approach influences students' development within each sustainability competency. Future work will also explore how the lived experiences of students impacts their career goals with the aim to understand disproportionate impacts of sustainability issues on diverse communities.

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**Appendix A: Grading rubric for Gala module evaluation**

Project title:

1. Content (80%)
    - (10%) Welcome page - frames the general context of the work well
    - (10%) Provides a clear, well-posed objective statement
    - (20%) Presents appropriate background on the technical or scientific state of the art
    - (20%) Presents appropriate technical description of the specific technology
    - (10%) Describes future needs and opportunities
    - (10%) Cites sources appropriately
2. Organization and style (20%)
    - (10%) Well organized
    - (10%) Clear presentation of material

Total: X/100

**Appendix B: Survey questionnaire**

1. I consent to participate in this study Y/N
2. Name
3. Email
4. Age
5. Are you an undergraduate, masters, or PhD student?
6. Year in program
7. Nationality / ethnicity (choose any you identify with)
8. How high would you rate yourself on collaborative skills before you created the case? (scale of 1-10, 1 very poor and 10 excellent)
9. How high would you rate yourself on collaborative skills after you created the case?
10. Use this space to elaborate on how the creation of this module did/did not impact your collaboration skills if you wish
11. How high would you rate yourself on problem definition before you created the case?
12. How high would you rate yourself on problem definition after you created the case?

13. Use this space to elaborate on how the creation of this module did/did not impact your ability to define sustainability problems if you wish
14. How high would you rate yourself on creativity before you created the case?
15. How do you rate yourself now on creativity after completing the case?
16. Use this space to elaborate on how the writing of this module did/did not impact your creativity if you wish
17. How high would you rate yourself on environmental/ social justice awareness before you created the case?
18. How do you rate yourself now on environmental/ social justice awareness after completing the case?
19. Use this space to elaborate on how the writing of this module did/did not impact your EJ / SJ awareness if you wish
20. How was your experience writing this case study? If you have written a term paper for any other course (engineering or otherwise) how does it compare with constructing a case study?

**Appendix C: Interview Questions - *Students***

1. How did you feel about the new problem-based case format?
2. What kind of guidelines would have been helpful as you were writing the case? Anything specifically to incorporate EJ and SJ perspectives?
3. Has this project changed your perspective on engineering solutions? How?
4. What has been your experience/exposure to sustainability topics in your core engineering classes in undergraduate and graduate courses? Is this course your first exposure to these topics?
5. Was this new format effective in relating your engineering knowledge to real-world environmental and social issues?
6. What is your relationship to environmental justice and social justice? How does that influence what you choose to learn about and study? (probes the relationship between self-image, personal experiences, educational / career pursuits, and learning outcomes)
7. What has been your biggest takeaway from thinking about sustainability and social justice in the engineering context?
8. Any final thoughts and/or reflections?
9. Consent script
10. Is there any specific information that you don't want us to share from this conversation?

**Appendix D: Interview questions - *Course instructor***

1. How long have you been teaching this subject?
2. What motivates you to implement sustainability and environmental justice in your class? As a professor in engineering, do you think there is enough emphasis on these topics in the curriculum?
3. What pedagogical strategies do you mostly use and why?
4. What strategies do you find most rewarding for yourself and your students?
5. What Environmental Justice / Social justice teaching methods would you like to apply in this class?
6. What do you see as the utility of these cases? Someone is looking to create a classroom library of the cases, what will he do with the cases?

7. How do you think the case-based approach affected student learning in your class?
8. Please share any other reflections.

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