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Engineering Just Futures: Preparing Undergraduate Engineers to Integrate Technical, Sociocultural, and Environmental Perspectives [Work-in-Progress]

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Engineering Just Futures: Preparing Engineers to Integrate Technical, Sociocultural, and Environmental Perspectives [Work in Progress]

Engineers of the future need to not only be technically skilled but also able to address complex problems that include social, cultural, ethical, and environmental dimensions. Undergraduate engineering education therefore needs to prioritize the diverse skills needed for complex problem-solving practice [1]-[3]. Traditionally, undergraduate engineering education programs have focused on technical training in the engineering sciences, to the exclusion of broader concerns [4]-[6]. There are, however, a growing number of programs that aim to expand engagement with social, cultural, and environmental dimensions of engineering. Across those efforts is the common vision of engineering as a *sociotechnical* practice [2],[7],[8].

Incorporating sociotechnical perspectives into engineering education not only prepares students for the complex problems of contemporary society, but also supports the ongoing project of broadening participation in engineering. The traditional technocentric vision of engineering often pushes students with nondominant identities away from engineering, undermining efforts to promote equity and opportunity within engineering education [9]-[11]. A more holistic educational approach can bring cultural relevance into engineering education to better serve and retain nondominant students while preparing them to address complex sociotechnical issues [12]-[14].

In undergraduate engineering programs at our institution, sociotechnical ways of thinking occur in relatively few courses, and are prominent only in a 2-credit course (titled “Professional Skills for Engineers”) that most students take during their second year. Research, however, indicates a single course is insufficient, and students need *sustained engagement* with sociocultural ideas throughout their studies [15], [16]. To expand our students' opportunities to engage with sociotechnical perspectives, we created the Engineering Just Futures (EJF) Fellowship program. Rather than modify formal educational experiences (e.g., by creating or modifying courses), the EJF program creates informal learning opportunities (described below) for student “Fellows” who are interested in deepening their knowledge and skills in the social, culture, and environmental dimensions of technology. The program brings together a diverse group of students (in terms of their social identities, lived experiences, and technical knowledge/interests) to collaboratively investigate what it means to pursue "just futures" in our professional practice.

As we implement the EJF program in a “pilot” form, our research examines how participating in the program develops Fellows’ sociotechnical ways of thinking. Through this research, we aim to contribute to the broader field of scholarship regarding how to integrate social, cultural, and environmental considerations into engineering education [17]-[19]. The research questions guiding our work are:

1. During the EJF program, what changes occur in the ways that Fellows think about the interactions between technology, society, culture, and the environment?
2. How do EJF Fellows utilize sociotechnical perspectives when carrying out engineering projects?
3. How do EJF Fellows’ sociotechnical perspectives interact with their motivations for studying engineering, career goals, and identities as engineers?
4. What are the educational and career trajectories of EJF Fellows who participate in the program?

We are especially interested in exploring how the EJF program promotes educational equity by examining how the program utilizes fellows' multiple social identities (e.g., race, gender) and backgrounds (e.g., first generation college student) as assets [20].

Program Structure

The EJF program included two elements, each of which spanned the academic year (fall & spring semesters) and occurred outside of the formal curriculum. Because these activities placed demands on participating students' time, we provided students with a stipend of $750 each semester, funded through an internal seed grant at our university.

The first element was a series of regularly occurring *seminars*, which occurred approximately every three weeks (5 per semester) for 60-90 minutes. The goal of the seminars was to introduce EJF Fellows to conceptual principles and illustrative examples for pursuing justice-oriented work in STEM [21]-[23]. The seminars included interactive presentations from the leadership team on topics such as inclusive design practices, stewardship of data, and environmental impacts. They also included visits from guest speakers who shared projects that involve complex interactions between researchers, designers, and communities. For instance, a faculty in Mechanical Engineering shared a current project that involved designing community-level geothermal power for a nearby indigenous community. After providing a brief technical overview, she discussed how she has solicited community feedback and concerns, then engaged Fellows in a conversation about how she might respond to and engage with the community. Table 1 provides an overview of the seminars that occurred during the program.

Table 1
Overview of EJF Seminar Sessions

Seminar 1: Welcome & Introductions	Initial community building activities, then considering what it means to pursue "just futures" by examining a series of cases.
Seminar 2: Working with Communities	**Guest speaker:** Tribal liaison who facilitates collaborations between climate researchers with indigenous communities.
Seminar 3: Engaging with Stakeholders	**Guest speaker:** Faculty member working on geothermal energy project with an indigenous community. Follow up: Exploration of issues related to stakeholder engagement with disability tech.
Seminar 4: Gathering Stakeholder Perspectives	**Guest speaker:** Faculty member working to deploy autonomous vehicles in a rural community.
Seminar 5: Data & Justice	Collaborative investigation of a series of case studies that illustrate the ethical significance of non-human subjects data.
Seminar 6: Value Sensitive Design	Introduction to Value Sensitive Design as an approach to stakeholder considerations, followed by an application of the approach to example situations introduced in previous seminars.
Seminar 7: Story Mapping	**Workshop:** Introduction to GIS Story Maps as a method of sharing team project work.
Seminar 8: Design Justice	In-depth case study of the social, economic, and technological battles around leaf blowers, illustrating the complex cultural histories and political inequalities that surround technological issues.
Seminar 9: Technoskepticism	"Technoskepticism" introduced as a throughline across all of the ideas presented during the seminars, and one more case study investigation of medical technology to illustrate the many dimensions of technology.

Seminar 10: Team Projects	Project teams shared the stories of their project work from the year.

The second EJF element was an ongoing team *project* that gave EJF Fellows opportunities to connect ideas from the seminars to real-world practice. The Fellows worked on their projects in interdisciplinary teams of three, assembled such that each team brought together Fellows from different disciplinary spaces. Each team was provided mentorship from one of the faculty members on the EJF leadership team and connected to one or more community partners. Table 2 provides an overview of the team projects.

Table 2

Overview of EJF Team Projects

Museum Accessibility: Working with the educational staff at a local natural history museum to improve the accessibility of the museum and provide a more inclusive visitor experience.
Climate Resiliency: Collaborating with a city sustainability office to develop a plan for a climate resilience center that can offer services related to extreme heat and severe storms.
Art and Language Models: Working with Fine Arts faculty and local artists to develop AI language models that help gallery visitors engage with art.
Autonomous Vehicles: Contributing to a federally funded research project that will bring an autonomous vehicle transportation system to a rural community.

EJF Participants

In the beginning of the Fall 2024 semester, we recruited a first cohort of 12 undergraduate students to participate as EJF Fellows. The fellows were selected on the basis of an online application and a follow-up interview conducted by our project team. The application asked students to describe their interest in the program and what they hoped to get out of the experience. The interviews further explored students' professional interests, experiences working in interdisciplinary teams, and how they would approach a technological problem in their local campus community. During the recruitment and selection process, we specifically sought students with an interest in and commitment to learning about how to pursue socially and environmentally just outcomes in their professional work. We also aimed to maximize the diversity of our cohort in terms of their technical knowledge, lived experiences, and identities. Demographic information about our participants is shown in Table 3. To protect the anonymity of our participants, participants' gender and racial identities are not shown. Among the group, 6 identified as men and 6 as women. In terms of racial identities, the group included individuals who identified as Caucasian/White, Filipino, Hispanic, Middle Eastern, and African American/Black (all demographic information was self-reported in an open-ended format).

Table 3

Participant Demographics

Participant ID	Academic Major(s)/*Minor(s)*	Year in school
S02	Environmental Design	Third Year
S03	Biomedical Engineering	Second Year
S04	Mechanical Engineering	Second Year
S05	Chemical Engineering / *Mathematics, Supply Chain Management*	Fourth Year

S06	Biomedical Engineering / *Psychology*	Third Year
S07	Environmental Sustainability / *Political Science*	Fourth Year
S08	Chemical Engineering	Third Year
S09	Industrial and Systems Engineering / *Economics*	Second Year
S10	Biomedical Engineering	Third Year
S11	Biomedical Engineering	Second Year
S12	Mechanical Engineering	Second Year

Methods

Our research utilizes a longitudinal qualitative case study methodology [24] in which each participating fellow represents a separate case, all of whom are bound by their common context of the EJF program. As a work in progress, we are drawing upon multiple data sources to develop thick descriptions of the fellows' learning experiences and changes in their thinking.

Data Sources

Data for our study are drawn from the initial interviews completed by EJF Fellows during the application process, Fellows' responses to a questionnaire that was given after each of the seminars, and a final interview completed at the end of academic year. The initial interview asked Fellows to describe their professional interests and goals, discuss a technological problem or issue that they would like to investigate, and respond to a scenario about a locally relevant technological system (ride-share electronic scooters on the university campus). The final interview included similar questions to explore changes in Fellows' thinking, but also included specific questions about their experiences in the EJF program, including what they gained from the seminars versus the projects, and suggestions they had about the program.

The post-seminar questionnaire included several closed-ended items that asked Fellows to report on how informative they found the seminar. They also included three open-ended items that asked them to report take-aways from the seminar, questions they are wondering about, and suggestions for the project team. These questionnaires were therefore used both as a data source for the research study as well as a source of actionable feedback to make real-time adjustments to the program so that we could meet our participants' interests.

Analysis

At the time of writing, we have only just completed the final interviews with our project participants, and so our analytical process is ongoing. We are developing in-depth case narratives for each of our participants that track their year-long experiences in the program, with a goal of identifying patterns across our participants as well as differences that can help us understand the differential impacts of the program. That longer-term analytical goal is ongoing, but for this work-in-progress, we can share an initial set of qualitative analyses that we have conducted that focus on overall themes within our data sources. As an initial step in our analytical process, we explored how Fellows described what they learned from their EJF experiences as well as difficulties that they experienced during the program. Our goal with this analysis was to identify the types of impacts the program had as well as the experiences that most contributed to those impacts.

We first analyzed Fellows' responses to the open-ended items on the post-seminar questionnaire. We used a thematic analysis process using open coding process [25, 32] to identify the insights and connections reported by the fellows after the seminars. We conducted these analyses concurrently with the program itself to gain insights into what ideas were resonating with our participants and how we could design future seminars to align with their emerging interests and curiosities. As we continued to run the seminars and gather more responses from the Fellows, we compared those new responses to the themes that we identified from their earlier questionnaires, refining and elaborating our analytical categories.

We then analyzed the interview data to build on the findings from our analysis of the questionnaire data. As we did so, we looked for ways that Fellows spoke to and expanded upon the themes identified during the prior phase of the analysis, while also looking for new ideas that could lead us to revise or add to our themes. Importantly, the interviews were a place where Fellows could describe their project experiences, which were not directly addressed in the questionnaires. The interviews thus allowed us to investigate the different contributions of those two components of the program.

Results

Across our participants' descriptions of what they gained from the EJF program, we identified several recurring themes. We also found that our participants described distinctly different learning experiences between the seminars and the projects, although there was some degree of mutual reinforcement. We begin by describing how the Fellows described the impacts of the seminars, which revolved around three major themes.

Seminar Impact 1: Engaging with Communities

An area of emphasis across multiple seminars was the importance of building relationships with members of the community that a project is meant to serve. Those ideas resonated with the Fellows, who expressed that many of the seminars expanded their understanding of what it means to truly work with communities in meaningful ways. The fellows' reflections on the seminars demonstrated how they are moving beyond the basic view that working with communities is important, toward a deeper understanding of the complex dynamics that underlie any partnership:

> Sometimes, a new technology might sound good to the people who develop it because they have the data and all the quantitative and qualitative facts involved but it is not worth much if the intended consumers do not trust the technology. Works needs to be done to find ways other than evidence backed up work to try to convince community partners why they should trust your product. (S11, Biomedical Engineering student)

The Fellows further noted how those complexities were rarely addressed during their coursework.

> It's taking into consideration the societies you're working with, their customs, what they want versus what you think would work, trust levels, all of those small details that go into curating solutions or coming up with ideas like I wasn't aware of before coming into EJF… . I feel like it has brought me a lot closer to what I've a mechanical engineer would look like in the field in terms of connecting with people and coming up with the whole ways to work thing. That practicality I feel like is a little missing in terms of the curriculum I go through every semester. (S04, Mechanical Engineering student)

One Fellow specifically noted the value of hearing from guest speakers who could present real examples of working with community-oriented projects:

> One thing that's great is that we get our guest speakers and we're getting to hear from people that are actively working on projects in the community, hearing the things that they are thinking through and trying to figure out. I don't think that ever really happens much in standard coursework. I think it's cool because we're not just seeing an end product, we're actually seeing them in the beginning stages as well. (S03, Biomedical Engineering student)

Seminar Impact 2: Considering Multiple Perspectives

The above quote from S11 not only addresses the importance of community engagement, but also the need to take seriously the different perspectives that stakeholders might have. Developing positive and trusting relationships with relevant community members is essential in an engineering project, but there is also a need for genuine *empathy* [26],[27]. Gathering perspectives that are different from one's own can help engineers gain more accurate understandings of the problems they are trying to solve. At times, those perspectives can reframe problems in entirely new ways. Several Fellows conveyed how deeply considering different perspectives needs to be part of any technological project.

> This made understand to pursue just futures, we need to create technology that doesn't try to fix problems that don't really exist for many. If we want to make the world accessible, rather than trying to get people to change or adapt to the majority, rather we should find ways to make the world more accessible for those that need it alongside us. This is demonstrated in the wheelchair example and the ramp rather than that stair wheelchair climber. (S12, Mechanical Engineering student)

> This seminar really focused on society/technology interactions, and who is at risk to be left out or benefitted by autonomous vehicle implementation. Specifically, the professor provided data on the citizen POV of autonomous vehicles, and I was shocked to see such a high level of distrust. It's easy to forget as STEM focused majors that many people aren't comfortable with this technology, or familiar with how it works and how it is developed. (S08, Chemical Engineering student)

The Fellows often identified the case studies that were presented during the seminars as being particularly valuable in terms of perspective-taking. The cases were presented in ways that elicited multiple valid perspectives, and the Fellows appreciated the ability to discuss their views with peers who held different ways of thinking about the issues.

> …being able to just share ideas on topics, like we had a seminar not so long ago about leaf blowers or just about maps, what are the ethics of creating maps and the effects that these may have on people's lives. I I feel like both being exposed to those topics and at the same time being able to discuss them with people who think in a similar way in a similar way, but also not in the sense that they think similarly as they are not trying to give an answer within the how do you call it, let's say inside the box, but it's more just trying to understand and further the comprehension of the framework itself in order to give a holistic and comprehensive answer regarding the issue being covered. So I think that listening to all those perspective is always, you know, feel like a very nourishing experience. (S05, Chemical Engineering student)

Seminar Impact 3: Accounting for Unintended Outcomes of Technology

Many of the case studies that we explored during the seminars showed how even when technologies are designed with good intentions, their effects in the real world are difficult to predict. New technologies interact with varied and complex social, cultural, and environment

systems, producing outcomes that their designers may not have intended or considered [28]. Yet even if anticipating the outcomes of technology is difficult, engineers nevertheless have a *responsibility* for the technologies they design and deploy [2], [23], [29]. This is yet another reason why building ongoing relationships and considering the perspectives of multiple community stakeholders is so essential.

Many Fellows described how the EJF program raised their awareness of the unintended consequences of technology. For instance, S02 (Environmental Design student) explained how "in trying to be an expert in something, it's important to know that what we might think is valuable and beneficial may not be perceived that way to the people we're trying to deliver to." S02 noted how this was illustrated by one of the presentations from a guest speakers:

> My understanding of the interactions between technology and society expanded when one of the fellows noticed that the technology Dr. Z wanted to deploy may cause more problems in the future.

As they gained awareness of those unintended problems, several Fellows described gaining a sense of their responsibility for the impacts of their work. For instance:

> …even if your intentions are pure, there can be negative impacts of whatever your project you do. For this session, we focused on who owns data, but it made me think about all the other volunteer projects that people have led. Even though they had a pure intention at the start, they did not take into account potential negative effects. It reminded me of various human-aid projects carried out in Africa, where the initial set up is done by the foreign organisation but the maintenance is left to Africans, who at no fault of theirs, have no knowledge of how to maintain it. All in all, this session made me realise that we have to take all possible outcomes into account as we conduct a project. (S09, Industrial & Systems Engineering student)

Team Projects as Turbulent, but Valuable

The team projects were intended to provide Fellows the opportunity to apply the theoretical ideas from the seminars to authentic work with communities. In some ways, the projects successfully built upon the three main themes from the seminars. S03, for instance, explained how the project was a "high point because it's a little more hands on, getting to apply the perspectives we consider in the seminars to the real community."

At the same time, though, the challenges of coordinating the work of the projects tended to dominate Fellows' experiences. Many of the projects proceeded much more slowly than the project team and the Fellows intended. As two of the Fellows explained:

> What was challenging goes along mostly with the project management side of things, like when are we going to meet, what are we going to discuss? Especially because in the beginning phases, it was more of an abstract. We were swimming in the dark trying to grasp onto something we all agreed to work on. (S04, Mechanical Engineering student)

> The challenge is when it's many people working on the same thing. It can be slow given that people have different responsibilities outside of that and probably not giving the same level of what is it priority over the project and everything. Someone will be well ahead on what we're doing, someone else is not, and you have to wait for them or step in to help and everything. That can slow the process. (S10, Biomedical Engineering student)

While the Fellows tended to describe their project experiences as turbulent and often frustrating, they many also recognized ways that they grew from those challenges:

> Even though the project isn't finished, I had hands on experience with trying to trying to work through certain obstacles that we had, and then also being able to be in touch and communicate with other people was a cool thing because I feel like it gave me insight as to how to go about communicating and keeping in contact (S07, Environmental Sustainability student)

> I would say that having to be in a group project, that is just kind of like such a struggle just by itself to meet. I feel like it has improved my scheduling skills because whenever you need to get them done, but then there's other things that you might need to prioritize, you need to know how you can move things around. (S05, Chemical Engineering student)

Thus, while the projects did not necessarily function exactly as intended, there were some instances in which they successfully built on the seminar themes and many students described them as valuable learning experiences.

Discussion

The preliminary results that we have presented here point to several influential aspects of the EJF program. Specifically, we identified several key messages that have resonated with the Fellows, all of which indicate that our participants are developing a fuller understanding of engineering as a sociotechnical practice [7]-[9]. Prior to the program, the Fellows likely recognized the importance of working with communities, taking multiple perspectives, and accounting for unintended consequences. However, when the Fellows spoke of their experiences in the program, they described how their understanding of that work has become far more nuanced as they have recognized the many complexities of sociotechnical problems. The case studies presented during the seminars helped to highlight those complexities. The Fellows also valued getting to hear from guest speakers who could speak to how they grappled with those complexities in their own work.

As we continue our analysis, our goal is to investigate the different learning trajectories and experiences of the Fellows. While they all spoke to the major themes presented above to some extent, there were also distinct differences in their experiences. There were especially differences across the team project experiences – in short, some groups were more successful than others in terms of collaborating and making progress toward their project objectives. While all the Fellows indicated that they learned something from their projects, their learning experiences were decidedly mixed. Our hope was that the projects would create opportunities for the Fellows to apply their emerging sociotechnical ideas to authentic situations – something that prior research has identified as challenging for students [16], [31]. This may have been true for some, but in other cases the turbulent nature of the projects likely got in the way. As we compare the Fellows' reflections on their projects with artifacts generated during their project work, we will gain a better understanding of the distinct role that the projects played in the EJF program.

As we continue our investigations, we hope to gain further insights into the kinds of learning experiences that best promote sociotechnical ways of thinking [17]-[19]. By operating outside the formal curriculum, the EJF Program created space to bring together students with diverse perspectives and technical backgrounds, which Fellows described as a key part of the program. By further exploring the successes and challenging of EJF, we hope to inform similar informal educational efforts as well as those within traditional classroom spaces.

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