ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #38043

Novel multimodal framework for embedding social justice education in technical engineering coursework

Ingrid Scheel

Ingrid Scheel is a Project Instructor at Oregon State University. She uses experiential methods to teach socio-technical content in engineering science and design courses. Her focus is systems engineering and program management. Scheel has experience in small business strategic planning and risk assessment, designing and deploying fiber optic sensors and sensing systems, prototype development, instrumentation, data acquisition and analysis, and reporting. Scheel contributes to the International Society for Optics and Photonics as a conference chair, editor, and author. She is the President of the Optical Society of America, Columbia Section, and works to forge strong connections between industry and academic research.

Gail Verdi

Dr. Gail Verdi is Executive Director of Kean University's School of Curriculum and Teaching, Associate Professor in the Department of Elementary, Middle, and Secondary Education, and Coordinator of Kean's Graduate TESOL Program. She currently serves on NABE's Research and Assessment SIG as an Executive Board member; and is a member of the Advisory Board for a 2021-2022 NSF Grant: "Embedding Equitable Design through Undergraduate Computing Curriculum" awarded to Dr. Patricia Morreale.

Lara Letaw

Inclusive design researcher and computer science instructor at Oregon State University

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Abstract

Students enrolled in undergraduate Engineering programs are becoming more diverse while engineering science curricula remain unchanged and outdated. Educators and instructional designers of Engineering Science must transform courses so that they are relevant and engaging to students who vary in gender, age, race, sexual orientation, neurodiversity, disability, alterability, and socioeconomic status. Shifting instruction to serve the needs of diverse populations can benefit all students. If institutions fail to meet the academic needs of learners, students might instead choose the increasingly available alternatives to formal education such as vocational and trade schools, apprenticeships, and self-paced free and paid resources. To help instructional designers make the needed shift, we synthesized three known techniques into a novel framework for engineering science curriculum delivery. We utilize: Writing-to-Learn activities, Inclusive Magnification (InclusiveMag/GenderMag) methods, and Engineering for Social Justice criteria. This framework allows plenty of space for fundamental engineering science coursework and results in a deeper understanding of those engineering concepts through the lens of real-world collaboration and contexts.

Introduction

Engineering is necessary for human survival and anyone who wants to be part of designing that survival deserves to participate. Instructional designers must create content that allows for teaching the fundamentals of a discipline and leaves space for cultivating and discussing new ideas. Underserved populations in engineering have been shown to stick with careers where they feel they have a social and global impact so incorporation of applications and examples into curriculum is essential [1, 2]. The multimodal framework presented in this paper demonstrates a way to emphasize the relationship between engineering and society while delivering technical content.

Isolating technical content devalues socio-technical connections often referred to as “soft” skills and “...misleads students to believe these skills are optional…” and unmerited [3, pg. 15]. Delivery of engineering science content utilizing the modules presented here will move integration of these necessary skills into students' technical material. Integrating diversity, equity, inclusion, belonging, and social justice (DEIB+SJ) in science and engineering education is a complex, multifaceted challenge. Fundamental technical curriculum changes generally require time, navigating emergence from complex systems, and university-specific strategies [4].

Integrating the evolving diction of social justice into engineering science courses might seem daunting. We present that this is not the case. The multimodal framework presented here shows synthesized use of three techniques to bookend existing learning material with a DEIB+SJ perspective. There are entire courses and majors on social justice so to be clear the DEIB+SJ content encouraged here is not comprehensive. However, faculty can adapt the techniques described here for use in any introductory engineering science course without needing to extend effort on new modules or reconstructing legacy curriculum.

Background

It is well documented that stress and anxiety can create “cognitive lockout” in students which detracts from their ability to grasp new concepts [5]. Teachers are invested in student success and one support pillar of that success is to facilitate a safe, respectful place for students to engage. By creating environments where students are made aware of how important it is to work with and across differences, we will graduate engineers who are ready to tackle highly complex challenges in a globalized workplace. We will graduate engineers aware and respectful of all those populations including but not limited to those protected by Title VII [6].

Inclusive practices are vital to the health of engineering education because exclusivity in STEM fields is a root cause of stagnation in innovative technologies. More diverse teams are directly tied to better outcomes [1]. It follows that a group of people with widely varied perspectives and interests will approach a problem from different angles and create more robust solutions. Specific, case-by-case, context-aware inclusive practices can bolster these teams and are presented here in a way that can readily be implemented into first-year engineering courses focused on any STEM field or subject. It is especially applicable to courses that include teaming or group work as an outcome.

Three rigorous techniques for student learning are synthesized in this multimodal framework: Writing-to-Learn, InclusiveMag/GenderMag, and Engineering for Social Justice criteria. Each technique in its original form supports student learning [7, 8, 2]. InclusiveMag focuses on eliminating accessibility barriers and bugs in software. Writing-to-Learn fosters meta-cognitive development and understanding. Engineering for Social Justice frames engineering problem sets in the context of the real world to mimic industry and engage students. These techniques are described in detail in this section.

Writing-to-learn

Writing-to-learn is a practical application of focused free-writing that facilitates deep understanding of concepts over time. Subject specific prompts are used as a platform for students to practice communicating what they are learning in a concrete medium. The goal of focused free-writing is to allow students to create their own progress repository. These are known as process logs and are extremely low stakes in terms of assessment. In no way does grammar, sentence structure, or diction play a role in the assessment of process logs.

Through writing-to-learn activities, students make meaning in composition and errors are a natural part of that learning process [8]. Instructional faculty must expect, prepare for, and accept without penalty these necessary errors in grammar. At the same time, faculty use writing-to-learn strategies to guide students toward fluent, clear, and correct writing through contextualized response. Students do not write to learn in a vacuum. Faculty guide students toward understanding through written and or spoken dialogue to foster cognition and focus on content over form [8, 9].

The low-stakes aspect of these assignments is essential for three reasons.

1. It allows instructional faculty to easily grade complete/incomplete assignments
2. Students explore and internalize new concepts without the stress of strict assessments based on objectively correct answers
3. It showcases that any language students use is welcome in the classroom

Language is an expression of individual identity and often a link between home-knowledge and academic-knowledge. Valuing home knowledge is important in the context of building upon foundational concepts [9, 10]. When students can bring their whole selves to class and express their curiosity in their own language without discrimination, student success increases [11]. The writing-to-learn activity presented in this paper is a modified process log where students were assigned weekly reflection assignments (focused free-writing) where they chose between topics such as: lecture content, the assigned reading, or projects. The benefit to student learning compounds over time using self-reflection and self-assessment [8, 12]. Additionally, instructors can review these materials to get to know students, identify shifts in students' thought and understanding of content, and reflect on their materials used.

InclusiveMag/GenderMag

The InclusiveMag methods are used to identify and eliminate bias "bugs" in software solutions. These methods involve "walking through" technology from the perspective of users with a variety of cognitive styles. The InclusiveMag meta-method is used to generate methods for specific diversity dimensions; GenderMag is one such method, for creating technology that is equally usable to all genders.

The evaluation benchmarks used in GenderMag are based on usability of technology to people with varying problem-solving [13]. At the heart of GenderMag are "cognitive styles" — ways people problem-solve differently depending on their motivations, attitudes toward risk, information processing styles, and technology self-efficacies. Extensive research has found that, statistically, cognitive styles cluster by gender. While individual cognitive styles can vary over time and depending on context, the statistical gender differences hold across different age ranges, technologies, and technology use cases. Cognitive styles are the foundation of the DEIB+SJ introductory material used in the focused free-writing prompts and class discussions of what engineering for social justice means.

Engineering for Social Justice criteria

Work at the Colorado School of Mines resulted in five criteria for creating inclusive classrooms and bolstering retention of underserved engineering students. The Engineering for Social Justice criteria is as follows:

1. Listen contextually [to student experience, feedback, and commentary]
2. Identify structural conditions [that affect student learning, success, and livelihood]
3. Increase opportunities and resources [for all students]

4. Reduce imposed risks and harms [on traditionally underserved populations such as queer, black, indigenous, disabled, and neurodiverse persons including but not limited to those protected by federal law]
5. Enhance human capability [2]

Enhancing human capability (criterion 5) is the goal of all preceding criteria [14]. The application of the Engineering for Social Justice criteria in this framework consists of lecture and supplemental materials that emphasize the existence of engineering within a larger human context. The writing-to-learn and InclusiveMag techniques described above are adapted to explicitly include Engineering for Social Justice criteria. The cognitive styles activities frame teaming across difference(s) as both increasing opportunity and reducing risk. Similarly, the process log prompts identify structural conditions by encouraging contextualization of engineering problems throughout the course.

Methods

The two essential elements in inclusive teaching instructional faculty can communicate with this framework are:

1. The presenter is an advocate and activist for underserved students in their classrooms
2. This material is worthwhile and mandatory for all engineers [3]

Delivery & Participants

The framework was delivered during an 11-week, intro-level "Design Engineering and Problem Solving" course at Oregon State University. The course consisted of two one-hour lecture sessions and one two-hour studio per week. Four studio sections with 25 students in each were designed to be a hybrid lab/recitation where students received instruction from faculty and teaching assistants. This time was used to work on weekly and multi-week projects. Minimal (less than ten minutes per lecture) time was used for the DEIB+SJ contextualization of engineering problems. The framework supplemented introductory technical content such as Excel, MATLAB, LTSpice, breadboarding, and Python programming.

Writing-to-Learn activities

Weekly focused free-writing process logs were assigned to assess student participation and level of engagement. They were useful for any immediate adjustment or adaptation of class content needed. The weekly logs mimic for a larger classroom setting the small-team Agile scrum-sprint process from project management best practices [15]. These assignments were due on Sunday night after each week of class to provide closure of prior content and occasionally act as a pre-survey for the next topic.

Since writing-to-learn techniques are foundational to cultivating understanding, they were utilized to explore student reactions to course content including the InclusiveMag/GenderMag methods and Engineering for Social Justice criteria expanded in subsequent sections. Prompts included questions about studio, lecture, homework, group work, group dynamics, course content, and student experience. A few example focused free-writing prompts are included here:

> What did you learn about your peers' cognitive styles?
> What did you learn about your cognitive style?
>
> Who is your customer?
> What does customer discovery have to do with bias reduction?
>
> Do you think reliability or efficiency is more important?
> What are unknown unknowns?
>
> How does policy relate to technology?
> What National Engineers Week event did you attend?
>
> Define user-centered design in your own words.
> Define human-centered design in your own words.
>
> Has your career path trajectory changed at all this term or this year?
> Final thoughts; feedback; frustrations?

InclusiveMag/GenderMag — Cognitive Slider Activity

The first and most effective step teaching faculty can take to create inclusive environments is to introduce themselves as a whole person who changes and adapts situationally [16]. This novel framework introduces cognition as a general concept on the first day of class from the perspective of how we process and make meaningful change with technology. This activity takes about ten minutes and sets an inclusive tone for the introductory syllabus-day lecture. The Cognitive Styles Slider introduction activity is based on the GenderMag personas' *facets* and is used to show how the instructor interfaces with new technology. Figure 1 shows an example of a completed cognitive slider representing the instructor. After this slider is introduced and explained, students participate by filling out their own slider.

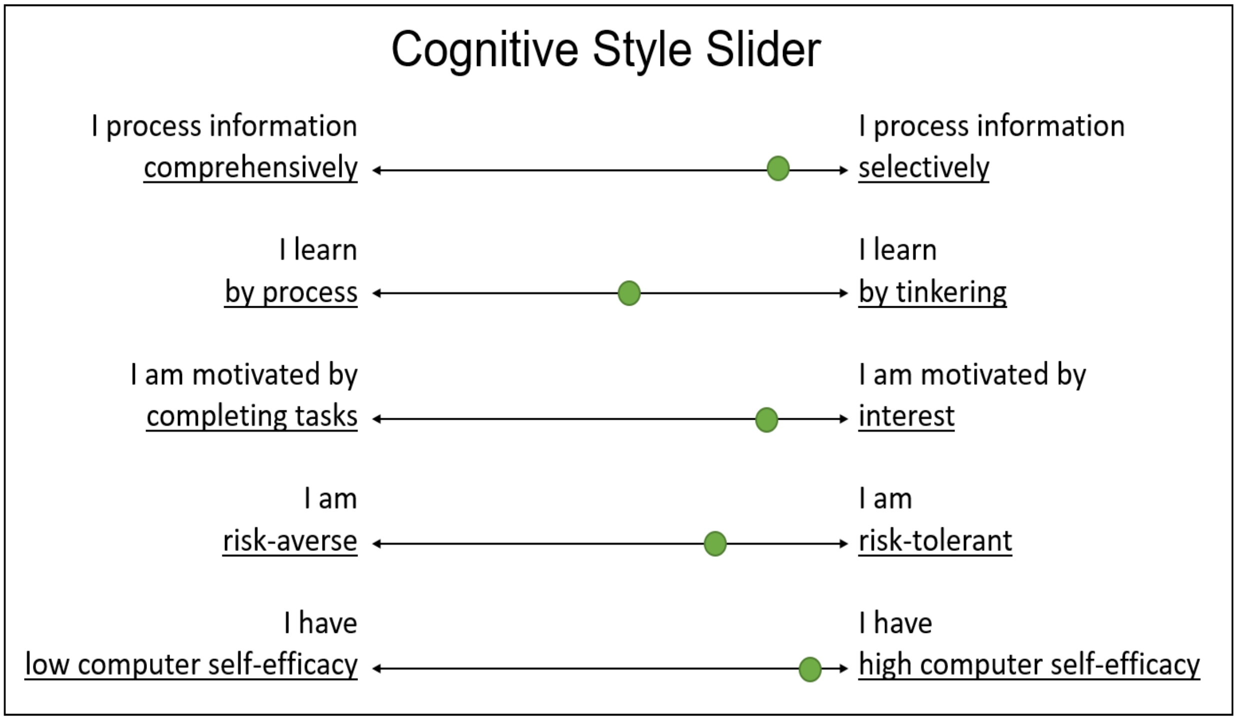

Figure 1. Cognitive Style Slider introduction activity for the first day of class. The instructor fills out this visual aid as a presentation piece. They then explain how they process information, learn, are motivated, tolerate risk, and use computers when interacting with new technology.

This activity is used to explore three main pieces of information:

1. There are facets or approaches through which human viewpoints are individual and unique
2. The slider must explicitly relate to one specific context
3. There is no one "right" answer

Through self-reflection students are encouraged to consider where they see themselves on the slider when interfacing with new technology. When complete, students are then prompted to turn to their neighbor and compare facets. Special attention should be paid to areas of similarity and difference between students. This can be done in pairs for smaller classes or groups of three for larger classes. This stage concludes with the instructor bringing the students back together for discussion. The main discussion points are:

- Not everyone is the same
- Similarities and differences are assets to a project team
- Research shows the more diverse a team the better the outcome

Students are then prompted to use a different marker/indicator to fill the slider out again from the perspective of preparing for an exam. It is important that the follow-up topic be chosen to contrast with interacting with new technology in a way that represents a power differential between the activities. The assumption is that when interfacing with new technology the students

are not observed or assessed. Changing the situation means the added layer of assessment will influence their approach to the situation. Alternative follow-up contexts may include doing taxes, completing homework, and preparing for an interview.
When complete, students are then prompted to compare facets for themselves between contexts. The main discussion points are:

- What (if any) facets changed due to circumstance?
- What stayed the same?
- Would your approach to the new circumstance be different in a year? Ten years?

To wrap up the instructor shows their own situational facets. Figure 3 shows an example of an instructor's self-assessment of interfacing with new technology compared to preparing lecture material. This is also an opportunity to provide a feedback loop such as an anonymous survey where students who do not want to be identified can express their concerns or criticisms of the activity and or discussion.

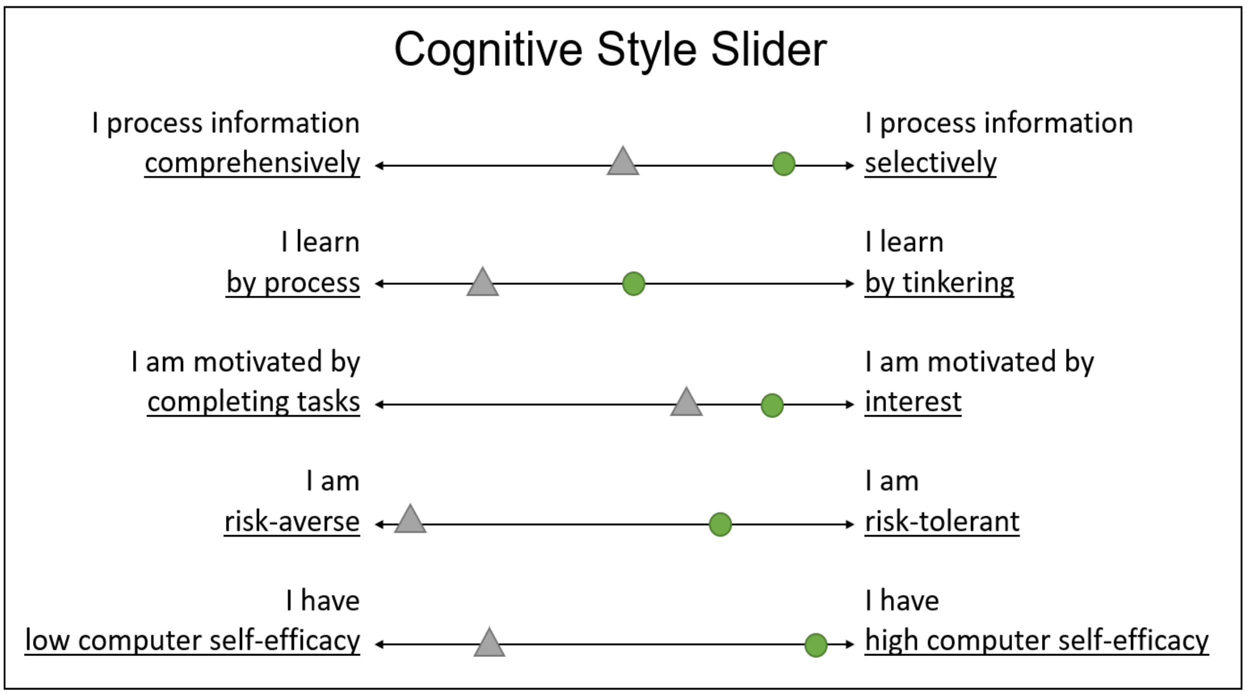

Figure 3. An example of a slider for teaching faculty based on interfacing with new technology (green dots) compared to preparing lecture (gray triangles) showing situational adaptation of information processing styles continue beyond being a student.

This foundational activity sets the tone for discussion throughout the term. Engineers are supposed to create the most comprehensive and robust solutions possible [17]. It follows that engineers must work in teams that consist of comprehensive representation and perspective. Redundancy of this concept is recommended on at least a biweekly basis throughout the course through class discussion, homework instruction, or activity. An example is shown in the next subsection of one type of follow up activity.

InclusiveMag/GenderMag — Bias Reduction Activity

This bias reduction activity reinforces the cognitive styles lecture content. In this activity, students learn how to use spreadsheet software and discuss in their groups the breadth of the cognitive styles spectrum they represent. Figure 4 shows an introductory assignment to spreadsheet software. Its use creates redundancy around cognitive styles, and students can choose a peer or two to work with. It can be used with newly formed groups or with assigned project groups. They learn how to maneuver around a spreadsheet, enter data, and highlight cells while exploring again how they interact with a new form of technology compared to their teammates. They can highlight cells with their own chosen color scheme to display their self-perceived cognitive style on a sliding scale from one to nine. The sliding scale differentiates this method from the legacy *Strengths* assessment tools which define human approaches in terms of binary "good" or "bad" traits that are rooted in norms of the dominant paradigm [18]. It is imperative that all possible responses to this activity are framed by the instructional team as assets.

Fill out this sheet by highlighting the numbers that most represent your behavior when introduced to a new form of technology.		Disagree Completely			Neither Agree Nor Disagree					Agree Completely
I am able to use a new technology when:		1	2	3	4	5	6	7	8	9
a	I have the built-in help for assistance.									
b	I have seen someone else using it before trying it myself.									
c	no one is around to help if I need it									
d	someone else has helped get me started.									
e	someone shows me how to do it first.									
f	I have used similar tech before, to do the same task.									
g	I have never used anything like it before.									

Google Sheets upload this file to your Google Drive, open it with Sheets, then File -> "Save as Google Sheet"
Student1
Student2
Common response

Figure 4. Bias reduction exercise where students fill out their answers to the questions working in pairs or small groups. Each student could choose a color (preferably a primary color) so they could identify where they are similar or different from their peers and note any overlap. The exercise was designed to foster metacognition and reinforce the introductory Cognitive Slider lecture.

The implementation of this activity in the first week's studio amplifies the cognitive styles slider lesson from a personal reflection into a teaming exercise. It teaches that teaming means appreciating the similarities and differences between team members.

Engineering for Social Justice Criteria

To graduate holistic engineers ready to tackle socio-technical problems in industry educators must stop distilling engineering homework problems. Lucena states, “The Problem is the problem,” meaning the distinction of engineering problems from the real-world application of their solutions creates a false sense of separation between the problem and how it must be solved [14]. The solution, when a problem is isolated from context, includes only numbers, forces, spring constants, or linear estimation and ignores that, ultimately, engineering goals center around customers, stakeholders, and communities. A brief example of presenting an engineering science homework problem with context intact — or "re-contextualizing” — is as follows:

> Manuel is a window washer working on a platform operating 200 feet off the ground on a 30-story building. Like most window washers in Denver, Manual is a Mexican immigrant who earns less than the legal minimum wage, has no health or accident insurance, and runs two daily shifts (his wife too) to pay for rent and food for a family of four. Without people like Manuel, the white-collar professional class, who works managing financial assets for big corporations, will not have a clear view of the Rocky Mountains. The platform is attached using pulley systems at the top of the building using a mobile fixture. *Determine the force exerted on the cables as a Cartesian vector. Additionally, determine the magnitude and coordinate direction angles of the resultant forces…* [2].

Educators need not contextualize every problem to get the message across to engineering students. Just like introducing the instructor’s cognitive style on the first day of class shows them as an advocate for underserved communities, talking about how a particular technical concept applies to industry and directly affects users and communities will show the students that it is essential to consider human-centered design as an engineer. This shows engineering students the immense ethical and communal responsibility of engineers in the field [3].

Results

Over the 11-week term student responses to process logs went from general identification of systemic issues and effects to specific exposition of personal experience and observation of course content in the real world. Initially, students expressed understanding of broad, fuzzily formed concepts. After practice teaming, their insight grew, and they began to identify as a part of the larger engineering community. They voiced ways they want to interact with the world and complex problems. They started to observe their place as first year and transfer students in the larger university and community landscape. The trend from impersonal generalization to personal lived experience was evident in participants who stuck with process logs the whole term. Two example quotes below from students exemplify how the first response tends to be outcome-oriented, written by a student who is summarizing an assumption and the second is reflective and based on the student’s experience engaging in engineering activities.

Week 4:

> I believe the interconnection between Engineers and non-engineers is only growing, and it is important that we learn to share and express our ideas and findings to those who may

> not be readily experts in our fields. – Engineering student

Week 9:

> Each person [in our team] had important breakthroughs [each week] and contributed in numerous different ways…it is important to listen to each person in the group because as a team we are more likely to come up with rational solutions. The power of five brains is far greater than the brain power of one. – Engineering student

This sequence of introductory exercises results in an effective lesson on how humans interact situationally. The cognitive style slider discussion culminates in an understanding of how one person's information processing approach can change due to the environment, social dynamics, and internal, external, or perceived pressures. The conclusion is that peer-to-peer comparison is important, but self-to-self comparison solidifies self-awareness and how a student is impacted by context.

Most students reflected on their experience in the cognitive style slider activity in aggregate with the bias reduction activity as essential to engineering practice. A quote from a student's submission the first week through their process log shows comprehension of how DEIB+SJ approaches expand solution spaces.

Week 1:

> Bias reduction is essential to practicing engineering because firstly, it opens up more ways to approach a problem, which is always helpful when taking on an engineering task. Thinking about a problem in more ways can also lead to more accessibility to new technology, which may help it grow and make more of an impact. – Engineering student

By the end of the term, even without bias reduction wording in the prompts. Students were still addressing these fundamental issues from the first week of class.

Week 10:

> As a woman in engineering, I have struggled to find support from teachers or peers in the field. However, Oregon State has provided more than enough support for me to excel in this major. Not only is there a community that exists specifically for women engineers, but I also live in a dorm surrounded by other women in STEM. Although there is still some bias that exists, especially among male students/teachers, I still feel support. In general, this term has opened my eyes to many job opportunities as well as the struggles of teamwork. – Engineering student 1

> I have started using the engineering checklist to help plan my school work out every week because whenever I go into a week with a plan I usually have a lot less stress at the end of the week…I really enjoyed the elevator [speech] I thought [it] was the best project over the whole term. I felt that incorporated some very important life skills like impromptu speaking, creative interpretation, and goal communication. I had an

> interview…for a project management internship position this summer and I was asked about what career path I'm thinking of pursuing and my answer was really close to my elevator speech. – Engineering student 2

End-of-term surveys went out to the first-year course registrants in the last week of classes. Over 90 percent of students in the course responded that course delivery using this multimodal framework supported their awareness of social justice, environmental issues, and the intersection of these topics in engineering. Over 85 percent of respondents expressed that this framework increased their desire to work in the field of socially responsible engineering. The full applicable dataset is shown in table 1.

Table 1. Post-Assessment survey results

My experience in this class…	**Total respondents**	**Strongly Agree/ Somewhat Agree**	**Somewhat disagree/ Strongly disagree**
…supported awareness of social justice	80	38/ 38	2/ 2
…supported awareness of environmental issues	80	35/ 40	0/ 1
…helped me understand the connection between environmental and social issues within engineering	80	44/ 31	2/ 3
…increased my desire to work in a job or do research in socially responsible engineering	80	36/ 34	3/ 7

Discussion

The multimodal framework presented here is an effective way to embed social justice education into technical engineering coursework. Recommended next steps include application of these techniques to engineering fundamentals courses, second- and third-year engineering science courses, and higher-level elective courses. The success of the class presented here in this context is a good start, but to determine portability of this framework it needs to be implemented in non-introductory courses and in courses of different engineering majors. It is designed to be cross-disciplinary and broadly applicable to faculty teaching packed engineering science curriculum.

Two major limitations were present during this deployment that need to be monitored and possibly modified over time. First, due to covid-19 safety protocols half the class often participated virtually or asynchronously rather than in person. Consequently, the course discussions especially around the middle and end of the term were limited to participants in the room with minimal engagement in the virtual chat. Second, process logs are designed to be continuous pieces of work that foster a relationship between students and instructors. Given the large number of students and total word count assigned per week this relationship was extended across an instructional team. In future, it would be ideal to form these process logs as a living document rather than weekly, separable reflection assignments. Prompts related to more specific technical content and redundant discussions that build on prior content would improve the evaluation of student responses over time. Supplemental group discussion forums in addition to the process logs are recommended so students have a shared space to post self-selected portions of their personal reflections.

Conclusion

The multimodal framework successfully engaged students through activities, writing prompts, self-reflection, studio projects, and lecture materials that focused on real world engineering contexts. The resources described in this paper are portable and applicable to all engineering fields and possibly other academic areas. Over the 11-week course student engagement level increased as did communication with the instructional team. After the course was complete students continued to follow up and give feedback. Work is ongoing to collect qualitative data and explore further improvements for future iterations.

Acknowledgements

This work has been informed by giants in the field of cognition and inclusive design research. The authors would like to especially thank Margaret Burnett and Sarah Perrault of Oregon State University for their prior work and unwavering support.

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