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Integrating Equity in the Systems Engineering Curriculum: A Pilot Study

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WIP: Integrating Equity in the Systems Engineering Curriculum

As engineering educators, it is our imperative to incorporate issues related to diversity, equity and inclusion (DEI) into our teaching. On the flip side, we must also strive to assess student performance with the same characteristics. Achieving both of these can be difficult, yet not insurmountable. The broad range of system engineering (SE) makes it rather adaptable to incorporating DEI due to the ability to cover systems ranging from purely mechanical and biological to ones which include more human elements such as social and political. Systems such as the latter were introduced into the undergraduate Industrial and Systems Engineering (ISE) curriculum to assess how DEI can be captured in the curriculum. The results obtained can be used to help shape a framework for immersion of DEI into the ISE curriculum.

Two pilot studies were performed as a work in process; the first was a recent senior project which designed qualitative and quantitative system models of homelessness in Philadelphia for the purposes of policy making and the second was a semester long course in systems thinking and dynamics. They were used as a means of piloting new non-traditional assessments and raising student awareness that DEI should be central in engineering practice. One main premise was not to teach the topics overtly, but rather raise DEI issues via activities. These in and out of class learning activities included things like role playing, self-assessments, case studies and impromptu polls.

From the teaching perspective, preliminary results show that students are aware of issues related to DEI, however, it is unclear whether or not there was an increase in student comprehension of its implications and the need for taking a more holistic approach to engineering. What did become apparent however, was the need for an increase in faculty training, a general awareness and acceptance of the validity of non-traditional assessments and projects as well as tools and methodologies for translating that into the curriculum.

Introduction

As educators we are compelled to incorporate practices which foster a diverse and inclusive environment and prepare students for success in a global society. In engineering, too often this goal is comprised mainly of efforts that aim to ensure more equitable distribution of race and gender in the student body and the faculty. While this is worthwhile in itself, we must be aware of the implications. Educating a diverse population to be successful in their career signals the need to utilize teaching practices and that allow all students to be successful and also to educate students about issues pertaining to diversity, equity and inclusion (DEI). Simple exposure to a diverse environment in the classroom does not fully prepare students to succeed in a similar real-world environment.

In order to best prepare students for post-graduation roles, we must incorporate DEI into our curriculum. Education in these issues promotes their awareness of the topic and allows them to explore their own implicit bias in a safe environment. Practicing our teaching with similar thought, we must assess the student outcomes in a manner which is reflective of our own understanding of these issues and aims to minimize performance gaps due to disparities between students.

Systems Engineering is an ideal platform to promote student awareness of global inequities in the world as well as explore internal biases. It is equally well-suited to apply more equitable assessment and instruction methodologies. This work in process is a pilot study embedding some non-traditional assessment methods as well as DEI topics within the coursework to assess the long-term goal of integrating it throughout the curriculum. They were performed through a junior level course in Systems Thinking and Modeling and a Senior Design Project, both required in the Industrial and Systems Engineering curriculum.

Background

DEI in the Classroom

The traditional engineering curriculum relies solely on teaching the nuts and bolts of what is thought to be needed as an engineer. Many experts agree that these courses do not adequately prepare students to enter today's engineering profession leaving them at a disadvantage [1] [2] [3]. They argue that what is needed is the ability to design and function in a diverse, global environment and that many are graduating with skills that are often in conflict with workplace requirements leaving them ill-equipped to be a fully functioning contributor.

As an example, we teach students to research the problem during the engineering design process, before developing potential solutions. This research typically consists of only those elements which relate to the engineering specifications of the problem and the subsequent requirements and constraints developed are measured via engineering equipment or tools. On the other hand, the practice of engineering can be considered a web of socio-technical tasks including things like technical coordination, human resources and problem solving in diverse environments [4] [5] [6]. To tackle today's engineering challenges, students must be made aware of societal issues, particularly with relation to injustice and inequity, and the human element which interacts with the problem at hand. Very often, topics such as social justice and ethics are thought of as tangential to the engineering curriculum, to be covered in other general education classes or not at all. This omission conveys to students the idea that these issues are separate from "real engineering" (or worse, inconsequential), lessening their ability to meet today's global challenges [7].

Many engineering educators will argue that it is not our place to instruct matters of social justice and inequity in the classroom – that this is accomplished in the non-engineering, general education curriculum. Yet in a typical engineering college, design projects both intra- and extra-curricular are based around social injustices often using Engineering for One Planet, Engineers without Borders, Engineers for a Sustainable World, or the National Academy of Engineering's 14 Grand Challenges as a backdrop to introduce the UN's Sustainable Development Goals. While these are certainly worthwhile, useful projects, one can argue that it is not enough to just tackle the design challenge without discussing the reasons the issue exists and arguably more importantly, possible implications of the solution. Often this leads to uncomfortable conversations which we are often disinclined to have in the classroom. Students know that the issues exist and they themselves often voice concerns over the absence of training or discussions on these types of issues in class [8]. By not addressing them outright and compartmentalizing

engineering as comprising only the quantitative piece without human interaction, we are doing a disservice to students.

There are positive benefits that document the effectiveness of instilling this mindset into the curriculum. One study showed that by incorporating topics such as implicit bias and diversity into a freshman engineering class, students reported a statistically significant higher likelihood of modifying their own behavior in a team setting [9]. Bielefeldt et al., reports that engineering instructors who incorporated more topics like social justice or poverty in the curriculum raised student awareness of ethical considerations [10]. In a case study, Eastman et al. [11], concludes that when classwork and research directly involve people of color students become more aware of their own internal biases and privilege. These issues need not be ignored in an engineering classroom and rather should be brought to the forefront when appropriate so as to not diminish their importance.

Assessing Equitably

Many institutions have put together task forces to address DEI issues campus-wide. One result of this has often been the allocation of additional resources to campus-based centers that can facilitate the development and implementation of non-traditional assessments and educational tools. However, these methodologies are often shunned by engineering faculty firstly because of the difficulty involved and secondly because they are thought to reduce the rigor required of an engineering student - that it may somehow lower the standards and outcomes. Yet the traditional manner of lecture and exams promotes inequality and disbenefits marginalized students [12] [13] [14]. These methods have been shown to favor non-diverse students hailing from middle-class environments with much stronger backgrounds in math and science [15]. Non-traditional tools that level the playing field and reduce performance due to disparity must be incorporated into the curriculum for both assessment and instruction if we are to prepare students for today's global challenges.

Recent efforts have shown positive evidence of utilizing equitable practices to teach and assess students as well as the increase in student learning and achievement of outcomes. Many of these courses follow Universal Design for Learning principles, whose intent is to make accessible pedagogical tools. As an example, in one study, three practices shown to be more equitable (eliminating the 0-100% grading scale, not including behaviors or homework in the final grade, and allowing for retakes on all exams) were applied in an Electrical and Computer Engineering course to understand their effect on student learning outcomes and performance. Results showed significant increases in performance in underrepresented groups with no loss in achievement of outcomes [16]. The creation of active learning modules to teach Finite Element Analysis resulted in an increase in student learning across all demographics and particularly benefitted reflective learners more than active or sensory learners [17]. Calibrated Peer Review (CPR)- a discipline non-specific online tool developed by Han [18] that facilitates writing assignments in courses – was used by Culver, et. al. In their lab course [19], the use of CPR was shown to not only increase student performance but significantly reduce disparity in grades across demographic groups. Angrave et.al. [20], utilize ClassTranscribe, an accessible video viewing system in various engineering courses -some as a primary source and others as a supplemental source. Both

groups show an increase in student outcomes and student feedback reports it to be moderately useful or greater for assignments and exam preparation.

Many educators choose to focus on reducing the inequities in engineering that particularly affect a single group or have tested an assessment form that resulted in enhanced performance by only a single group. Harteveld, et.al., [21] report an increase in female interest in pursuing and applying foundational knowledge after learning geotechnical engineering via a gamification approach. By reducing the impact of exams on final grades, Cotner and Ballen find that the use of other assessment types reduces the gap in performance between female and males [22].

Utilizing assessments and teaching in ways that deviate from the traditional is not an easy task, particularly in engineering. The development of these teaching materials, assessments and student resources is time-consuming and considerably more difficult in quantitative courses which don't often lend themselves easily to class discussions and active learning techniques.

Using Systems Engineering as Platform for DEI

Systems Engineering is an ideal platform to incorporate issues such as DEI as it is virtually impossible to discuss a system today without incorporating some human element. When designing systems for humans, incorporating DEI into the education of the designer can mitigate the effects that bias can play into the design. Awareness of one's own mental models and the issues that face the end systems user, particular when it may be a diverse population, will allow for more universal design that does not continue to privilege the same populations and exacerbate the inequities of others [23]. Handley and Marnewick [24] augment an existing competency model that incorporates elements of global competencies to now include DEI principles. They apply it to a systems engineering graduate program and suggest modifying material content, student interactions (classroom activities) and the teaching environment (methods, practice and atmosphere) simultaneously. In this pilot study, a senior design project in Industrial and Systems Engineering and a course in Systems Thinking and Modeling course were used to test the effects of utilizing non-traditional assessments and the change in student perceptions by incorporating DEI topics.

Case Studies

This research piloted two cases of incorporating DEI topics in the classroom and one non-traditional assessment methodology. A Senior Design Project and a course in Systems Thinking and Modeling were utilized. Each of these cases are documented.

Case I: DEI In The Curriculum, Senior Design Project

Concept

At the time this was conducted, the capstone senior design sequence was the same for all engineering students, requiring a one credit seminar, followed by a two and then a three credit senior design course. The seminar is taken in the junior year and in it, all potential projects for the following year are pooled. Students rank and bid on projects that require their specific discipline and are eventually assigned to a team. The last two courses (Senior Design I and II)

follow the same progression regardless of major with the same set deliverables required at the same time.

The goal of this senior design project was to provide a tool that would accurately simulate the behavior of housing insecurity in the city of Philadelphia for the purpose of aiding organizations in policy-making by being able to predict the effect of potential programming and interventions. As this is not a traditional type of engineering senior design project, the level of student interest that would be seen was unknown and assumed to be low. Astonishingly, almost 33% of the ISE class bid on the project, and resulted in a team of four students with some degree of diversity (50% male and mixed ethnicities).

Methodology

Ultimately, the team chose a system dynamics model as the most viable solution. They broke the research process down into three phases: 1-developing a causal model, 2-translating that into a quantitative system dynamics model and 3-validating the model. Although the results are all observational or from student reflections, phase I was by far the most interesting and revealing. The qualitative causal model involved research to understand the determinants of housing insecurity and homelessness. As the engineering literature in this area is sparse, they needed to synthesize their social science research into major determinants and arrive at a final qualitative causal model.

Results

It is typically challenging to engage students in DEI activities if they are offered as extra-curricular activities. Having a two semester project enabled students to really delve into the factors to contributing housing insecurity. The project was focused in Philadelphia, and as the University is situated in a lower income section of the city, they experienced the effects of it daily and could very much relate to the situation. Having a platform in which to frame their conversations allowed for a much deeper conversation on the topic. It was interesting to observe the shift in attitude as they uncovered more and more research from the social science area. Student reflections and audience comments received after their final presentation were also very telling from an engineering community (students and faculty alike):

- "I never realized there were so many extraneous factors that went into homelessness"
- "I didn't know there was a difference between housing insecurity and homelessness"
- "This was a great and unique way for the engineering community to help out in an area we don't normally serve"

<u>Case II: DEI In the Curriculum, Systems Thinking and Modeling Course</u>

Concept

This junior level course introduces systems thinking and system dynamics computer modeling using Vensim. Major topics covered include causal mapping, stock and flow models, sensitivity analysis and leverage points. As the ISE program began in 2018, this was only the third time it was offered. Before this offering, the context of lectures and examples revolves around traditional applications such as population, finance and workforce. However, the latest offering

utilized mostly non-traditional areas as we modeled things like gun violence, environmental disasters, and pandemics. Not only did these lend themselves easily to class discussions about diversity and equity but they also enabled some non-traditional activities and assessments. Two activities that allowed students to explore mental models were undertaken in this course.

Course Activities

In the first activity, to introduce mental models, students anonymously submitted key words that came to them when the word "migration" was mentioned. This was followed by some recent headlines about migrants and migration, all of which used words or figures like "tidal wave" or similar.

The second activity aimed to reinforce mental models. It was centered around an epidemiology model they built incorporating mask mandates, retail closures and travel restrictions. It was taken from an MIT OpenCourseware on System Dynamics [25] and required students to construct a stock and flow model taken. Given the initial conditions, students assessed the levels of healthy and sick people over time and then assumed the role of a lawmaker and needed to determine what restrictions, if any, should be in place to keep the outbreak at a relatively even level.

Results

The two activities about mental models were informative. Student responses to the word migration were all negative and included items like: "influx", "Mexico", "border crossings", "tent cities", "homeless", "unemployed". After sharing many negative headlines and pictures used to portray migration, a discussion ensued about the effect of media on our opinions and how, unconsciously, our mental models are formed by external factors unconsciously. This led to a rather lengthy discussion about migration, and allowed one student to share his experience of arriving in the U.S. and although he is here on a student visa, the negativity he encounters in the city and University due to his Hispanic-looking background.

In the epidemiology model, students had the ability to adjust the number of population interactions but needed to justify how this would be accomplished. Responses included various combinations of mask mandates, percentage of retail closures and travel restrictions. Many students were initially concerned with only bringing down the death stock in the stock and flow model, however, this prompted a foreign student to share his experience of not being able to see his family for three years, leading to a very valuable conversation about the effects of policy making on the population.

In both of these activities, the DEI component was not assessed directly as part of the course grade although future plans include incorporating this into the grading rubric. Anecdotally, there were some very valuable learning moments for both the students and instructor.

Case III: Non-Traditional Assessment, Systems Thinking and Modeling Course

Concept

Throughout the term, student teams of four were allowed to select a topic to study and ultimately model over the course of the semester. Deliverables included a qualitative causal model, quantitative system dynamics model, identification of leverage points and model verification.

Methodology

For the team presentation of the causal model, each non-presenting team played a particular stakeholder, previously identified by the presenting team. These stakeholders were often in conflict and the teams were required to critically evaluate the presentation through that lens and comment on specifically with that stakeholder's viewpoints. The rubric used to assess that is shown in Table 1.

Results

This project allowed students to research and select their own topic to study. Mid-semester, as each team presented their causal model, the non-presenting teams each acted as a particular stakeholder assigned relevant to the presentation (and evaluated according to the rubric in Table 1). Most of the projects contained some aspects of human element. Three of the four teams modeled topics that were largely taken from existing data such as the bankruptcy of Blockbuster which allowed for some discussion of equity such as layoffs. One team chose to model the decline in college enrollment at their own university. For this team, the stakeholders were students, college administrators and parents. Students debated the pros and cons of tuition increases, college and university scholarships and recruitment efforts and in particular a discussion of gender and racially targeted scholarships aimed at increasing underserved populations.

This course offering was a change from how it had been taught in the past, as I strove to weave DEI issues into the class discussions, examples and assessments and most results are anecdotal. The course outcomes do show an increase in student self-assessed confidence as seen in Table 2. Future plans include a more planned inclusion of DEI in the course with introduction and reinforcement activities and more robust assessment of the outcomes.

Table 2: Pre and Post Student Self-Assessment of Course Outcomes

	% Scoring "Strongly Agree" or "Agree"	
Prompt	Pre (n=17)	Post (n=12)
How confident are you in your ability to develop an appropriate design, justify an approach and develop a solution appropriate for the environment in which it is to be utilized?	86	92
How confident are you in your ability to effectively communicate in a verbal format with various audiences?	86	92
How confident are you in your ability to effectively communicate in a written format with various audiences?	86	92
Overall, I learned a great deal from this course.	77	100

Conclusions

The Accreditation Board for Engineering and Technology (ABET) has amended their General Criteria to now include DEI principles with the aim of ensuring students have the "ability to function effectively on a team whose members together provide leadership, create a collaborative

and inclusive environment, establish goals, plan tasks and meet objectives. Further, the faculty criteria now states that "program faculty must demonstrate awareness and abilities appropriate to providing an equitable and inclusive environment for its students and knowledge of appropriate institutional policies on diversity, equity and inclusion [25]. There is an urgent need for engineering education to morph both teaching content and practices to graduate students equipped to handle today's challenges.

The examples presented are a work in progress and as such is not intended to show the end product of how DEI can be incorporated into the curriculum. A more logical, well thought out plan is needed with where and how it will be introduced and reinforced throughout the curriculum. Topics should be introduced early on and reinforced throughout various courses. Nonetheless, it is a good illustration of how DEI components can be incorporated into the classroom relatively easily and arguably more important, the eagerness of students to engage in and discuss such issues.

Criteria	Ratings			
	Expert-4 pts	**Proficient-3 pts**	**Apprentice-2 pts**	**Novice-1 pts**
Active Listening/Response (as presenter)	Team demonstrates active listening skills by providing thoughtful responses addressing specific aspects of other students' statements, including asking questions	Team demonstrates active listening skills by providing thoughtful responses to other students' statements, but asks few or no questions	Team demonstrates active listening skills by listening attentively while other students speak, but provides little or no response to any statements.	Team provides no indication they are listening to other students, by speaking while others speak, or repeating what others have already stated.
Etiquette	The team acts as a model participant, speaking only at appropriate times, and showing respect to all other participants.	Team acts appropriately during the meeting, typically speaking at appropriate times, and showing respect to other participants.	Team occasionally speaks out of turn or interrupts another student, but shows respect to other participants.	Team occasionally speaks out of turn or interrupts another student, or otherwise shows disrespect of other participants
Participation	Team actively participates, speaking multiple times, adding new information/evidence each time	Team actively participates, speaking more than once, adding new information/evidence each time	Team actively participates, speaking more than once, but repeats information each time.	Team does not participate
Active Listening /Response (as non-presenter)	Team demonstrates active listening skills by providing thoughtful responses addressing specific aspects of other students' statements, including asking questions	Team demonstrates active listening skills by providing thoughtful responses to other students' statements, but asks few or no questions	Team demonstrates active listening skills by listening attentively while other students speak, but provides little or no response to any statements.	Team provides no indication they are listening to other students, by speaking while others speak, or repeating what others have already stated.
Preparedness (presenter)	Team is extremely familiar with their role as decision maker and uses specific evidence to support their arguments	Team is extremely familiar with their role as decision makers, and uses some evidence to support their arguments	Team is somewhat familiar with their role as decision makers, but provides little or no evidence to support their arguments	Team is not familiar with their role as decision makers, and provides no evidence to support any statements/arguments they make

Table 1: Rubric Used for Stakeholder Role-Playing (as presenter and listener)

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