Responsible innovation in biomedical engineering: a value sensitive design intervention

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***Abstract*— It is essential to educate a generation of the engineering workforce that considers human values such as human welfare, freedom from bias, universal usability, and equity in all the stages of engineering product development. These values should be included alongside conventional technical requirements (e.g., performance effectiveness, reliability and resilience, compliance with technical standards and protocols). One approach to address the need for incorporation of human values in the design is to provide students with frequent learning opportunities to practice adopting an inclusive mindset in their interpersonal interactions as well as in their engineering analytical problem-solving and design practices. We designed an intervention to foster student awareness of non-inclusive designs in engineering and medicine, their own tendencies towards these biases, and the impacts of these biases on neglected demographics. An important component of this intervention was embedding it into the teaching of analytical content: we implemented it in a middle-year analytical course with a heavy focus on model-based learning and mathematical modeling, as opposed to a separate unit or course on inclusion or ethics, or a senior design course. Although we created this intervention in a biomedical engineering course, it could be used in any science and engineering class. In this paper we focus on the intervention's rationale, its implementation process, and how our approach was guided by the concepts of entrepreneurial mindset and value sensitive design. We report what medical fields were included in students' brainstorming of flawed designs. We also investigate whether the identity of students (gender, ethnicity) has any relation with the affected stakeholders in the flawed designs in brainstorming examples of biased designs, developing a personal experience story, and a team exercise in developing a case study and proposed solution. Also, we summarize an investigation of whether exposure to classmates' direct experiences of non-inclusive designs (in contrast to hypothetical experiences) affected their choice of a stakeholder in their project's topic. Finally, we explore whether students focused on a case study topic which created value for *themselves* or whether they focused on a topic which *benefitted others* (and thus, whether empathy resulted from this intervention in inclusive design).**

Keywords—entrepreneurial mindset, value sensitive design, inclusive medical devices, biomedical engineering, story telling

I. Introduction

We created an intervention in a required analytically-focused biomedical engineering course called "Conservation Principles in Biomedical Engineering." Our goal was to increase awareness about non-inclusive products. This is part of a larger effort within our department to help our students develop an entrepreneurial mindset (EM), which is characterized by being an engineer who habitually seeks to create value for others, and society in general [1]–[4].Our design of this intervention was informed by Value Sensitive Design (VSD) [5], a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process. VSD employs an integrative and iterative tripartite methodology, consisting of conceptual, empirical, and technical investigation [6], [7]. VSD has been used for information technology [8],[9] and global healthcare [10]. It has a potential to be used in medical science and biomedical engineering. This course is taught using the problem-solving studio (PSS) approach [11], a highly interactive apprenticeship learning environment in which students work in a stable team of four for the entire semester. Through this semester-long project composed of a series of individual and team exercises, students are challenged to identify cases of non-inclusive designs in biomedical engineering and their impact(s) on the stakeholders. Then they use the engineering fundamentals (learned in this class or any engineering principles they are familiar with) to propose an improvement to that non-inclusive design.

We expect that this increased awareness will motivate them to find ways to minimize the impact of their personal biases on their engineering design work by, for example, working with teams of people who differ from themselves in terms of their life experiences, perspectives, and skills. Ultimately, we hope that students will leave with a greater appreciation for how to use their engineering skills to create value for others.

II. Intervention's rationale

A. *Demand for inclusive design and responsible innovation*

The values used by engineers to design a product or process can significantly affect the stakeholders. The stakeholders could be the direct users of the designs or the people who are indirectly affected by them [6], [7]. Incorporation of all stakeholders' values will result in a product that is useful for everybody. If

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only the values of a specific group (target stakeholders) are considered in a process, it will likely result in a non-inclusive design. This non-inclusive design can be useless or even harmful for the rest of users, the "neglected stakeholders." The individuals, demographic groups, classes in the society, and institutions that are affected by the design to any extent should be accounted for in all steps of the design process. The values of these stakeholders should be identified and prioritized. For example, by accounting for sex and gender analysis in the design of an experiment, the scientific discovery can have a more effective experimental design and more equitable outcomes [12] for a population of men *and* women[1]. Just within the subfield of biomedical engineering, unaddressed biases have led to situations with serious health outcomes including examples such as (1) not including women's anatomy and physiology in the design of joint implants resulting in irreversible health issues, especially given the fact that women form more than 65% of joint replacement patients[13], (2) pulse-oximeters that read the saturation of peripheral oxygen (SpO_2) levels of patients with darker skin 8% lower than the real value, which can have fatal consequences for patients especially at the time of COVID-19 pandemic [14], (3) left-handed surgeons who do not receive appropriate equipment during training [15], and (4) facial recognition systems do not register the pain expressions of patients with dementia [16].

B. *Lack of attention to middle-years course interventions*

The task of creating value for the end-users and consideration of their demands is normally the focus of introductory design-based courses [17]–[19] or culminating senior capstone experiences or senior projects [20], [21]. Traditionally the focus of middle-years courses is on technical content and analytical procedures [22] There have been some efforts to propose a list of potential hypothetical modifications which incorporate universal designs [23] for product development into middle-years undergraduate courses, such as considering the needs of people with disabilities in the designs[24]. However, the bulk of this literature is focused on introductory design-based courses or senior projects. Without explicitly developing inclusion skills in the context of analytical and technical practices during these middle-years courses, students might consider including diverse users and teammates only in specific contexts, or they are at risk of not being able to transfer inclusive solutions to new engineering contexts. How might instructors integrate inclusive design learning goals into these courses without adding even more material into already content-packed classes? This paper presents an ongoing effort as one attempt to answer this question.

III. METHOD AND APPROACH

We have been implementing this intervention with its current structure since Fall 2020. Here, we present data from 88 students who participated in this intervention and consented to share their work for research. All the data collection and research activities in this research project have been approved by the Institutional Review Board in Georgia Institute of Technology.

This project has two learning objectives: a cognitive one and an affective one (see Table I). The cognitive learning objective is that students experience Entrepreneurial Mindset [4] by focusing on *problem finding*. Problem finding is an underappreciated topic, but it is a prerequisite for creating value. Our goal is to raise students' awareness of the existence of many non-inclusive designs. Non-inclusive designs are great places to find opportunities to create value. The affective learning objective is for students to use stories to help them better empathize with the people who were excluded from the benefits of, or even harmed by, the non-inclusive design. This is in order to motivate students (and others) to take action by designing more inclusively, and to gain awareness of the power of story as a way to motivate others to buy in to their ideas. These two objectives are achieved via a three-pronged intervention. There is a hook for each objective, there is a problem-finding portion of the exercise, and there is a value creation portion of the exercise.

The Hook (Assignment Phase: Brainstorming and Personal Experience Story). The project began by challenging students to work on their own to look for examples of biased/flawed biomedical engineering designs. Cognitively, this served to introduce the problem of non-inclusive designs. For the affective part of our learning objective to create a hook, we asked our students to write a story about a personal experience of a non-inclusive medical design or engineering product. We shared instructions for technical details of story writing with them. They had the option of writing about an experience that had happened to themselves, a family member, a friend, or a person they know. Alternatively, they were able to use a hypothetical character, or a pseudonym, if they preferred. By having students tell a personal story we hoped to make the impact of bias in engineering design seem more real to them, and to increase their intrinsic motivation and sense of relatedness to the project. Each student identified three examples of biased or flawed biomedical engineering designs and a story of personal experience.

Problem Finding (From Personal Experience Story and Brainstorming to Case Study). Next, students shared their Personal Experience Stories and the Brainstorming examples they found interesting with their teammates. Together they discussed the importance and impact of each design, both on a personal and societal level. As a team they then identified one flawed/biased engineering design that they wanted to learn more about. They created a Case Study to inform and motivate members of the lay public (Case Study; cognitive objective). After creation of their Case Study, students were asked to write a second story about how the flawed design has negatively impacted an individual or group of people, to illustrate awareness in an emotionally evocative and concrete way. This story could be about a real event related to the topic of their Case Study or a creative story about a hypothetical person who experienced the bias that they worked on in their Case Study (Awareness Story; affective objective).

[1] By extension, including other gender identity categories will encompass more inclusive gender-identity populations, such as non-binary individuals.

TABLE I
INCLUSIVE DESIGN ANALYSIS INTERVENTION LEARNING OBJECTIVES

Learning Objective	**The Hook**	**Problem Finding**	**Value Creation**
Cognitive	**Brainstorming:** Introduce problem of non-inclusive designs	**Case Study:** Find and critique existing design	**Proposal:** Analyze and propose a more inclusive design
Affective	**Personal Experience Story:** Harm to self, or a person they know	**Awareness Story:** Harm to a specific person	**Technical Story:** Good done for a specific person

Value Creation (Proposal Phase): In the last part of the intervention each team expanded their work and proposed recommendations for pursuing future designs and/or research efforts that would help create value for people who are not currently positively impacted, or perhaps are even negatively impacted, by the current design (Proposal; cognitive objective). Next, students wrote a story for a professional audience indicating the positive transformation the user would have if they received the modifications they proposed. The story should be able to motivate the professional audience to invest resources into creating and implementing the new design that will create value for the previously disenfranchised group. It should help the listener see and emotionally feel the impact that the new design will have on others (Technical Story; affective objective). Fig 1 displays students moving through the assignment structure.

Across all three phases assignments were analyzed, first identifying the "neglected stakeholder," and second coding whether the source of bias was due to ethnicity (Student of Color, White Student), gender (Female, Male), age (Youth, Elderly), or physiological/social difference (e.g., obesity, SES, body frame size, etc.; Has v. Not). In this paper, we present results from the Brainstorming, Personal Experience Story, and the Case Study & Proposal.

Research Questions (RQs):

1. During the Brainstorming assignment, what areas of medical field(s) were included in flawed designs identified by students?
2. During the Brainstorming assignment, is there a relationship between students' own gender and ethnicity and the source of bias that they identify in the neglected stakeholders of the flawed designs?

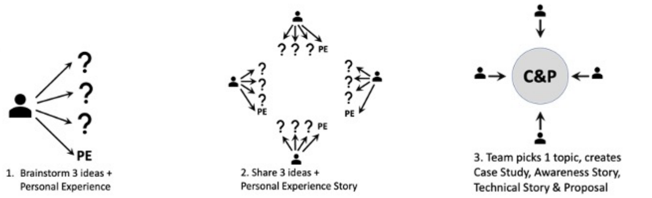

Fig 1. The assignment structure: Initially students Brainstorm individually and write a Personal Experience Story, then share these with team members, and finally the team picks one topic that is important for all members to work on as their project (Case Study, Awareness Story, Technical Story, and Proposal).

3. During the Personal Experience Story assignment, is there a relationship between students' own gender and ethnicity and the source of bias that they identify in the neglected stakeholders in their stories?
4. During the Case Study & Proposal assignment, is there a relationship between students' own gender and ethnicity and the source of bias that they identify in the neglected stakeholders in their Case Study & Proposal?
5. Is there a relationship between the type of bias the students focused on in their Personal Experience Stories and the type of bias the team chose to focus on in their Case Study & Proposal?
6. In the Case Study & Proposal assignment, did students focus on creating value for the flawed designs that *they* had personally experienced, or did they focus on creating value for *others* due developing empathy via team members' stories?

IV. RESULTS AND DISCUSSION

In this manuscript we present data from 88 students who participated in this intervention and consented to share their work for research. Students were asked to self-identify their sex/gender, race/ethnicity, and age (see Table II-a). The students' age ranged from 18-21, with an average age of 18.7 years (sd=.82). Almost 66% of students identified as female, and about 34% as male. None of our students responded as transgender, non-binary/non-conforming, or prefer not to respond. About 60% of these students identified as students of color (11% identified their ethnicity as Black/African American, 9% as East Asian, 11% as Hispanic/LatinX, 27% as South Asian), and almost 41% as White/Caucasian. None of our students identified as other racial categories. More detailed distribution and breakdown of students' identity based on sex/gender and ethnicity/race is listed in Table II-a. In this work, our analyses focused on gender and ethnicity, but we acknowledge that there are many other aspects of identity that should be considered in future work, including socioeconomical status, family background, country of birth, parental education, etc.

TABLE II-a
DEMOGRAPHICS OF STUDENT PARTICIPANTS

	n	%
Total:	88	
Age		
18 years	44	50.0%
19 years	30	34.1%
20+ years	14	15.9%
Gender		
female	58	65.9%
male	30	34.1%
Ethnicity		
Black/African-American	10	11.4%
East Asian	8	9.1%
Hispanic/LatinX	10	11.3%
South Asian	24	27.2%
White/Caucasian	36	40.1%

RQ1. In the Brainstorming phase of the intervention students explored various fields of medicine such as pharmaceutical industry, biomedical engineering, medical data management, general healthcare, orthopedics, dental care, cardiology, hematology, emergency medicine, diagnosis process, OB-GYN, and neurology. They were curious about various design types within those fields such as medical devices, implants, treatments, drugs, and algorithm/process.

RQ2: Students' own gender and ethnicity and relationship to source of bias for stakeholder in the Brainstorming phase. We asked students to identify the stakeholder(s) that were negatively affected by those designs and elaborate which aspect(s) of the stakeholders' identity were neglected in the design process causing harm for them. They shared cases that affected people because of their race/ethnicity (51.5%), sex/gender (36.7%), social/physical status (8.0%), and age (3.8%) (see Table II-b).

To study the effect of students' own identity on the cases that they are interested in via brainstorming, we conducted 2-way analyses of student identity (gender; ethnicity) and the stakeholders' disparity in their cases (coded for whether the disparity was based on gender, age, social/physical characteristics, or ethnicity; see Table III). We performed Chi square tests with significance level of .05 or less ($\alpha = 0.05$). For both the students' gender as well as their ethnicity, we were not able to reject the null hypothesis that there was no difference between the groups. There was no statistically significant difference between the female and male students and their identification of ethnicity, gender, age, or physical/social characteristics of the stakeholders in their cases (gender: χ^2 (3)=1.16, p<.77), nor was there a statistically significant difference between the students of color and the white students (χ^2 (3)=1.39 , p<.71).

RQ3: Students' own gender and ethnicity and relationship to source of bias for stakeholder in their individual Personal Experience Stories.

In the next phase of the intervention, students shared their Brainstorming about biased designs and their Personal Stories about real people with their teammates (n=88). Our students shared stories about people affected by a non-inclusive design because of their social/physical status (36.4%), gender (26.1%), ethnicity (25.0%), and age (12.5%); see Table IV. There were some gender and ethnicity differences between students. Female students and white students wrote stories with stakeholder characters with social/physical differences most often (43% of female students had this source of bias, and 41.7% of white students), and few stories of stakeholders with age differences (8.6% of female students, and 8.3% of white students). Male students and students of color wrote stories with approximately the same number of stakeholder sources of bias across all four codes. However, these differences were not statistically significant at the .05 level (Gender: χ^2 (3)=4.67, p<.20; Ethnicity: χ^2 (3)=2.58, p<.47).

TABLE II-b
DEMOGRAPHICS OF CHARACTER STAKEHOLDERS IN STUDY ASSIGNMENTS: BRAINSTORMING (3 PER STUDENT), PERSONAL EXPERIENCE STORY, AND CASE STUDY & PROPOSAL (COLUMN %S)

Disparity Based on:	**Brainstorming 3 Biases**	**Personal Experience Story**	**Case Study & Proposal**
	n=264	**n=88**	**n=88**
Gender	36.7%	26.1%	33.0%
Ethnicity	51.5%	25.0%	15.9%
Social/ Physical Status	8.0%	36.4%	36.4%
Age	3.8%	12.5%	14.8%

TABLE III
STUDENTS SOURCE OF BIAS IN BRAINSTORMING AS A FUNCTION OF THEIR OWN GENDER AND ETHNICITY

Disparity based on:	**Gender**		**Ethnicity**	
	Female (n=174, 65.9%)	***Male (n=90, 34.1%)***	***Students of Color (n=156, 59.1%)***	***White Students (n=108, 40.9%)***
Ethnicity (n=136, 51.5%)	51.7%	51.1%	51.9%	50.9%
Gender (n=98, 37.1%)	35.6%	40.0%	35.2%	39.8%
Age (n=10, 3.8%)	4.0%	3.3%	3.9%	3.7%
Social/physical characteristics (n=20, 7.6%)	8.6%	5.6%	9.0%	5.6%
	χ^2 (3)=1.16, p<.76		χ^2 (3)=1.39, p<.71	

Table IV
STUDENTS SOURCE OF BIAS IN CRAFTING A PERSONAL EXPERIENCE STORY AS A FUNCTION OF THEIR OWN GENDER AND ETHNICITY

Disparity based on:	**Gender**		**Ethnicity**	
	Female (n=58)	***Male (n=30)***	***Students of Color (n=52)***	***White Students (n=36)***
Ethnicity (n=22, 25.0%)	22.4%	30.0%	28.9%	19.4%
Gender (n=23, 26.1%)	25.9%	26.7%	23.1%	30.6%
Age (n=11, 12.5%)	8.6%	20.0%	15.4%	8.33%
Social/physical characteristics (n=32, 36.4%)	43.1%	23.3%	32.7%	41.7%
	$\chi2(3)$=4.67, p<.20		$\chi2(3)$=2.58, p<.47	

Students then worked together to choose one story to move forward with to compose a Case Study and to propose a more inclusive design (the Proposals). In this work student project topics focused on people affected by a non-inclusive design because of their social/physical status (36.4%), gender (33%), ethnicity (15.9%), and age (14.8%). Table V shows the percent of gender and ethnicity breakdowns of students and the case study's stakeholder source of bias. Female student cases tended to focus on ethnicity bias and social/physical bias, and about one third of male case studies focused on social/physical biases with an even distribution amongst the remaining sources of bias. These differences were not statistically significant ($\chi2(3)=4.82$, $p<.19$). With respect to ethnicity, students of color wrote case studies focusing on gender and physical/social sources of bias, while for case studies from white students, forty percent focused on physical/social sources of bias, with 15-25% spread across the remaining three sources of bias. These differences were not statistically significant either ($\chi2(3)=1.84$, $p<.61$). (See Table V).

RQ5. During the team case study and proposal phase, is there a relationship between students' personal experience of bias (vs. teammates' experiences of bias) and the source of bias that they identify in the neglected stakeholders in the project's topic?

Our data analysis showed that 73% students chose the topic for their project (Case Study & Proposal) based on stakeholder sources of bias that were experienced by students *within* their group (see Table VI), either as a personal experience ("self"), a family member's experience ("family"), or a friend's experience ("friend"). For these case studies where the sources of bias were experienced by a team member, about 36% of the cases focused on social/physical design biases, 34% focused on gender biases, and 18% focused on ethnicity biases and 13% focused on age biases. For the 27% of cases developed by teams where the biases were hypothetical (i.e., not experienced by team members, family, or friends), similarly, about 38% of the cases focused on social/physical design biases, 29% focused on gender biases, and 21% of the cases focused on age biases and 13% on ethnicity. This difference was not statistically significant at the .05 level (χ^2 (3)=3.65, $p<.30$).

Table V
SOURCE OF BIAS IN CASE STUDY & PROPOSAL SELECTED BY TEAM, AS A FUNCTION OF STUDENTS' OWN GENDER AND ETHNICITY

Disparity based on:	Gender		Ethnicity	
	Female (n=58)	***Male (n=30)***	***Students of Color (n=52)***	***White Students (n=36)***
Ethnicity (n=14, 15.9%)	12.1%	23.3%	15.4%	16.7%
Gender (n=29, 33.0%)	39.7%	20.0%	38.5%	25.0%
Age (n=13, 14.8%)	12.1%	20.0%	13.5%	16.7%
Social/physical characteristics (n=32, 36.4%)	36.2%	36.7%	32.7%	41.7%
	χ^2 (3)=4.82, p<.19		χ^2 (3)=1.84, p<.61	

RQ6. In the Case Study & Proposal phase, do students focus on creating value for the flawed designs that they had personally experienced, or do they focus on creating values for others due to development of empathy via sharing stories with teammates?

As we saw in RQ5 results and Table VI, the impact of creating stories become more vivid by knowing that 73% of these students chose to help the neglected stakeholders whom they learned about via a teammate shared story or knowing about a loved one affected by a bias. Only 27 % of those students selected a topic that was not experienced within the team. We were pleased to see that in general, as a group the teams decided to focus on cases and solutions that held personal implications for some members of the team, choosing to focus on creating value with empathy instead of for hypothetical people. Figure 2 displays the distribution. For the team-selected case studies where the sources of bias were experienced by a team member, 20% shared a story about self, 33% reported an experience of a family member, 14% reported a story about a friend, and 33% reported a story about a hypothetical character.

TABLE VI
SOURCE OF BIAS IN CASE STUDY & PROPOSAL BY TEAM AS A FUNCTION OF WHETHER STORY CAME FROM EXPERIENCE OF A STUDENT WITHIN THE TEAM.

Disparity based on:	**Experienced by Team Members (n=64, 72.7%)**	**Not Experienced by Team Members (n=24, 27.3%)**
Ethnicity (n=14, 15.9%)	17.2%	12.5%
Gender (n=29, 33.0%)	34.4%	29.2%
Age (n=13, 14.8%)	12.5%	20.8%
Social/physical characteristics (n=32, 36.4%)	35.9%	37.5%
	χ^2 (3)=3.65, p<.30	

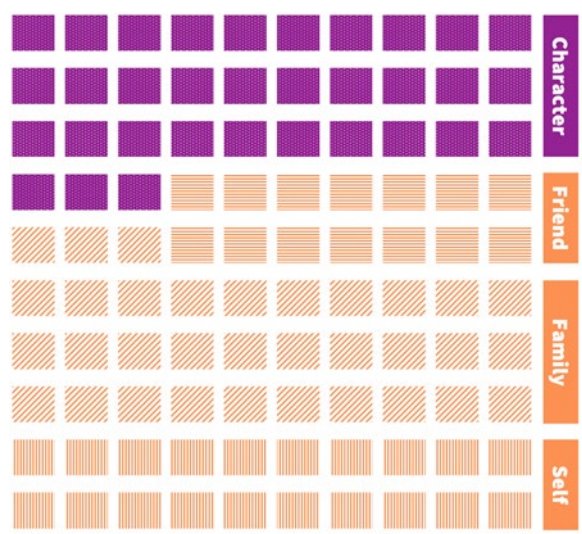

Fig 2. Value and empathy: Progression of source of bias from personal experience story to team project's Case Study & Proposal phase

Another view into the impact of sharing stories with teammates (as opposed to doing the project individually) can be determined by comparing the sources of bias as students moved from Brainstorming, to sharing Personal Experience stories, to the final topics of projects selected by teams in the Case Study & Proposal. Table VII shows Chi Square statistics for these three comparisons. Table II-a has the progression of sources of bias through these three intervention points. In the Brainstorming assignment, there were relatively few examples of age bias and of social/physical biases. By sharing their personal stories, students moved to a more even distribution across these four categories of bias. All of these Chi square tests approached significance or were significant (see Table VII), although some of the assumptions re. expected values for Chi square tests were violated for two of the three comparisons. We are nonetheless intrigued by these exploratory results and look forward to future research.

V. Conclusions

Since students were able to identify many examples of bias in a short period of time, we are confident that there is a large demand for developing a framework for responsible design, and that we have a model for delivering an effective intervention. The demand for such a framework has been discussed in other fields of engineering such as geoengineering [25], and in this work we are describing our initial effort in the field of biomedical engineering and medical science. Non-inclusive designs could result in discrimination when the engineers do not consider the outcome-relevant information, and instead incorporate irrelevant demographic assumptions. There are two main factors that can escalate this discrimination: noise (number of errors made in the decision making) and bias (the degree to which errors disproportionately favor one group over another) [26]. In this intervention our students focused on the bias in designs and not the existing noise. In all the cases that our students were able to analyze, errors in assumptions took place in a way that illustrated a demographic group at a disadvantage. Then they proposed solutions to reduce the errors that can favor one group over other groups.

Although these results are brief and partial, we can see that students were able to consider bias in their consideration of biomedical designs and the creation of their conceptual models. This will increase the sense of relatedness (by knowing the affected people) and autonomy (by selecting their own projects' topic) and at some level competency because they learn about possible applications of their work.

We include three exemplar quotes from students Personal Experience Stories here:

> "Many east Asians find it difficult to put contacts in.' Unlike most people, touching my eye was not the hardest part. Instead, opening my eyes big enough to be able to place the contacts on them was actually the hardest part. According to the doctor, like many people of east Asian descent, I possessed what is known as an epicanthic fold on each eye."

TABLE VII
SOURCES OF BIAS IN BRAINSTORMING, PERSONAL EXPERIENCE STORIES, AND CASE STUDY & PROPOSALS.

Assignment:	**Chi Square Results**
Brainstorming v. Personal Experience	χ^2 (9)=20.07 , p<.02*
Brainstorming v. Case Study & Proposal	χ^2 (9)=14.80 , p<.10*
Personal Experience Story v. Case Study & Proposal	χ^2 (9)=47.01 , p<.0001

*Note: some cells have low expected values.

> "People with darker skin tone are diagnosed less accurately for skin cancer.' Based on the original diagram, we improved it by introducing the "pigmentation test" system. The purpose of this system is to make the device recognize the skin type of any input image: both for the data samples inputting and for the suspected patients' images uploaded into the device."

> "Prozac can have dangerous side effects – mostly for women." I was dizzy, nauseous, and sweaty which at "first" I thought it was just an unusual reaction after the ride, but I have never had issues before. Then I was getting chest pain and it got harder to breath. Apparently, I had many risk factors, but the main cause was found to be my new antidepressant medication. I couldn't believe that the medication that seemed to be working so well could cause that bad of a side effect."

After cross referencing the cases that our students are interested in, the stories of Personal Experience of exposure to bias, and the topic of final project (Case Studies & Proposals) the groups created, we observed that 72% of the students were motivated based on the empathy they formed for a person they know, or they learned about. This conclusion was drawn from the current cohort. We are expecting to reach more conclusive results by extending our analysis and data collection.

Of course, no project can be perfectly suitable for every human being, and every study and/or design must have its limits; however, these limits and biases can be conscious and openly acknowledged. The intentional exclusion of a group of people is something that can and should be avoided. Building awareness of this is the goal of our Case Study intervention.

VI. Future work

As we continue this work, we look forward to several additional research efforts. For example, we inferred the creation of intrinsic motivation and empathy by analyzing the choices students made for their project. We plan to more directly assess the extent to which this project promotes students' intrinsic motivation and empathy using validated instruments for these constructs, such as those based on self-determination theory.

The focus of this paper was to elaborate on the intervention itself. For this purpose, only two aspects of student's identity were analyzed. In future work we intend to include additional dimensions of students' identities.

The identity of a stakeholder of a design is multi-dimensional, and they might be in disadvantage due to multiple aspects of their identity. We acknowledge this, and we do our best to incorporate such analysis in our future work.

In future iterations of this intervention, we will provide students with a framework for how to design inclusively: Universal Design's 7 principles, Responsible Engineering Toolkit: Harms Modeling [27]. We would also like to help students understand how stories promote value creation. Zaki's model of empathy posits that stories promote motivational empathy, which increases buy-in and action [28]. This work may be a fruitful source for operationalizing this.

At the end of the course, we asked "Our hope was that the project would be a meaningful learning experience for you. Was it? and explain why? "Over 93% of the participants said it was meaningful. Representative quotes from their reflections include:

> "It wasn't just about something for the class, it also had a meaningful impact and helped us discover a case of bias in the medical world which I think is really cool."

> "I think that as engineers, it is important to interconnect our learning to our outside world, and this project gave us a glimpse of that."

> "I learned a lot about the drug and the importance of including many different people in trials so ensure there is no bias. The hardest part was created the engineering diagram."

> "We took a problem that exists in the real world and used some of the new concepts we learned in class to create solutions."

These reflections demonstrate that this intervention helps students learn how to create value with their engineering design skills. In the end, we are excited that by doing this sort of awareness-building of inclusive engineering practices at multiple points throughout the degree pathway, we are helping increase the inclusive design skills of future biomedical engineers. We additionally look forward to continuing to disseminate results of these teaching and learning efforts, and to leaving a trail of ideas that other instructors can refer to in later courses.

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REFERENCES

[1] A. Y. Huang-Saad, C. S. Morton, and J. C. Libarkin, "Entrepreneurship Assessment in Higher Education: A Research Review for Engineering Education Researchers," *Journal of Engineering Education*, vol. 107, no. 2, pp. 263–290, 2018, doi: https://doi.org/10.1002/jee.20197.

[2] S. E. Zappe, S. L. Cutler, and L. Gase, "A Systematic Review of the Impacts of Entrepreneurial Support Programs in Science, Technology, Engineering, and Math Fields," *Entrepreneurship Education and Pedagogy*, p. 25151274211040424, Sep. 2021, doi: 10.1177/25151274211040422.

[3] A. Olson, D. Melton, and M. Johnson, "KEEN Top Resources: The basics of EM in a single card," *Engineering Unleashed*, Oct. 07, 2020.

[4] L. Bosman and S. Fernhaber, *Teaching the Entrepreneurial Mindset to Engineers*. Cham: Springer International Publishing, 2018. doi: 10.1007/978-3-319-61412-0.

[5] D. G. Hendry, B. Friedman, and S. Ballard, "Value sensitive design as a formative framework," *Ethics and Information Technology*, vol. 23, no. 1, pp. 39–44, Mar. 2021, doi: 10.1007/s10676-021-09579-x.

[6] B. Friedman, P. H. Kahn, A. Borning, and A. Huldtgren, "Value sensitive design and information systems," in *Early engagement and new technologies: Opening up the laboratory*, Springer, 2013, pp. 55–95.

[7] B. Friedman, P. Kahn, and A. Borning, "Value sensitive design: Theory and methods," *University of Washington technical report*, vol. 2, p. 12, 2002.

[8] M. K. Feister, C. B. Zoltowski, P. M. Buzzanell, and D. H. Torres, "Integrating ethical considerations in design," *ASEE Annual Conference and Exposition, Conference Proceedings*, vol. 2016-June. ASEE Conferences, New Orleans, Louisiana, 2016. doi: 10.18260/p.25804.

[9] J. van den Hoven, "ICT and value sensitive design," in *The information society: Innovation, legitimacy, ethics and democracy in honor of Professor Jacques Berleur SJ*, Springer, 2007, pp. 67–72.

[10] R. Walton and B. DeRenzi, "Value-sensitive design and health care in Africa," *IEEE Transactions on Professional Communication*, vol. 52, no. 4, pp. 346–358, 2009.

[11] J. M. le Doux and A. A. Waller, "The Problem Solving Studio: An Apprenticeship Environment for Aspiring Engineers.," *Advances in Engineering Education*, vol. 5, no. 3, p. n3, 2016.

[12] C. Tannenbaum, R. P. Ellis, F. Eyssel, J. Zou, and L. Schiebinger, "Sex and gender analysis improves science and engineering," *Nature*, vol. 575, no. 7781, pp. 137–146, 2019, doi: 10.1038/s41586-019-1657-6.

[13] K. Hutchison, "Gender Bias in Medical Implant Design and Use: A Type of Moral Aggregation Problem?," *Hypatia*, vol. 34, no. 3, pp. 570–591, 2019, doi: 10.1111/hypa.12483.

[14] M. W. Sjoding, R. P. Dickson, T. J. Iwashyna, S. E. Gay, and T. S. Valley, "Racial Bias in Pulse Oximetry Measurement," *New England Journal of Medicine*, vol. 383, no. 25, pp. 2477–2478, 2020, doi: 10.1056/nejmc2029240.

[15] P. S. Adusumilli, C. Kell, J.-H. Chang, S. Tuorto, and I. M. Leitman, “Left-handed surgeons: Are they left out?,” *Current Surgery*, vol. 61, no. 6, pp. 587–591, 2004, doi: https://doi.org/10.1016/j.cursur.2004.05.022.

[16] B. Taati *et al.*, “Algorithmic Bias in Clinical Populations—Evaluating and Improving Facial Analysis Technology in Older Adults With Dementia,” *IEEE Access*, vol. 7, pp. 25527–25534, 2019, doi: 10.1109/ACCESS.2019.2900022.

[17] C. Gunnarsson, C. Birch, and D. G. Hendricks, “Work in progress: Curriculum on diversity and ethics: Impact in an introductory bioengineering course,” *ASEE Annual Conference and Exposition, Conference Proceedings*. ASEE Conferences, Tampa, Florida, 2019. doi: 10.18260/1-2--32340.

[18] M. Nezafati, M. Chua, and J. M. LeDoux, “Work in progress: A case study of integrating inclusive engineering skills into a middle-years biomedical engineering course via model-based reasoning,” *ASEE Annual Conference and Exposition, Conference Proceedings*, vol. 2020-June. ASEE Conferences, Virtual On line , 2020. doi: 10.18260/1-2--35517.

[19] M. Nezafati, J. le Doux, K. D. Pierre, and K. T. Shook, “WIP: Integration of Inclusive Mindset in a Middle-Year Biomedical Engineering Course: a Study Over Healthcare Disparities via Story-Driven Learning,” Jul. 2021.

[20] J. Cezeaux, T. Keyser, E. Haffner, A. Kaboray, and C. Hasenjager, “Introducing universal design concepts in an interdisciplinary laboratory project,” *ASEE Annual Conference and Exposition, Conference Proceedings*. ASEE Conferences, Pittsburgh, Pennsylvania, 2008. doi: 10.18260/1-2--4037.

[21] M. Nasir, D. K. Kleinke, and M. McClelland, “Multidisciplinary patient-centered capstone senior design projects,” *ASEE Annual Conference and Exposition, Conference Proceedings*, vol. 2016-June. ASEE Conferences, New Orleans, Louisiana, 2016. doi: 10.18260/p.25764.

[22] S. M. Lord and J. C. Chen, “Curriculum Design in the Middle Years,” in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds. Cambridge: Cambridge University Press, 2014, pp. 181–200. doi: DOI: 10.1017/CBO9781139013451.014.

[23] S. Burgstahler, “Universal Design: Process, Principles, and Applications How to apply universal design to any product or environment,” *Disabilities, Opportunities, Internetworking, and Technology*, p. 4, 2015, [Online]. Available: http://www.washington.edu/doit/universal-design-process-principles-and-applications

[24] B. Blaser, K. M. Steele, and S. E. Burgstahler, “Including universal design in engineering courses to attract diverse students,” *ASEE Annual Conference and Exposition, Conference Proceedings*, vol. 122nd ASEE, no. 122nd ASEE Annual Conference and Exposition: Making Value for Society. ASEE Conferences, Seattle, Washington, 2015. doi: 10.18260/p.24272.

[25] R. Owen, J. Stilgoe, P. Macnaghten, M. Gorman, E. Fisher, and D. Guston, “A Framework for Responsible Innovation,” *Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society*, vol. 42, pp. 27–50, 2013, doi: 10.1002/9781118551424.ch2.

[26] J. R. Axt and C. K. Lai, “Reducing discrimination: A bias versus noise perspective.,” *Journal of Personality and Social Psychology*, vol. 117, no. 1. American Psychological Association, Axt, Jordan R.: Social Science Research Institute, Duke University, 334 Blackwell Street #320, Durham, NC, US, 27701, jordan.axt@duke.edu, pp. 26–49, 2019. doi: 10.1037/pspa0000153.

[27] R. Null, *Universal design: Principles and models*. CRC Press, 2013.

[28] J. Zaki, “Empathy: a motivated account.,” *Psychol Bull*, vol. 140, no. 6, p. 1608, 2014.