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Work in progress: a case study of integrating inclusive engineering skills into a middle-years biomedical engineering course via model-based reasoning

Dr. Maysam Nezafati, Georgia Institute of Technology

I am a lecturer in the department of biomedical engineering at Georgia institute of technology /Emory University. I have been working on educational research since 2016. My main focus is on problem based learning core courses. But specifically I work on inclusive model based reasoning and interpersonal skills. I have a Phd in bioelectronics and also do research in functional MRI, with the focus on functional network analysis and working memory.

Ms. Mel Chua, Georgia Institute of Technology

Mel Chua (melchua.com) is a contagiously enthusiastic hacker, scholar, dancer, bimodal polyglot, and perpetual motion machine. She started out in electrical/computer engineering and spent several years wrangling large distributed technical teams in the open source software and hardware world before returning to academia. Mel's research focuses on learning in hacker/maker communities, faculty development, embodied and critical postmodern qualitative research methodologies, and prototyping alternate ontologies of curricular culture in engineering education.

Prof. Joseph M LeDoux, Georgia Institute of Technology

Joe Le Doux is the Associate Chair for Undergraduate Learning and Experience in the Department of Biomedical Engineering at Georgia Tech and Emory University. Dr. Le Doux's research interests in engineering education focus on problem-solving, diagrammatic reasoning, and on the socio-cognitive aspects of the flipped and blended learning environments.

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Abstract

As engineering educators prepare increasingly diverse cohorts of students to tackle complex global challenges, the need for engineers with inclusive mindsets has become more apparent. One aspect of inclusion is the awareness of our potential for biases in the models we create of the world -- engineering models that go on to influence the technologies we produce.

This paper presents a work-in-progress case study of an intervention in a middle-years analytical course with a heavy focus on mathematical modeling. The intervention is designed to make students aware of biases in model base learning, their own tendencies towards these kinds of biases, and the sorts of impacts these biases can have on real populations. An important component of the intervention is that it is embedded into the teaching of analytical content, rather than being an additional unit on "inclusion" that remains separate from quantitative work.

The gap of awareness regarding bias in engineering processes

Engineers must be aware of biases and assumptions that shape the products they create, as this has engineering ethics implications on how their work impacts the world (Dyrud, 2017; Feister, et. al., 2016). Within our own subfield of biomedical engineering, unaddressed biases have led to situations such as left-handed surgeons not receiving appropriate equipment during training (Adusumilli et. al, 2004), facial recognition systems not registering the pain expressions of dementia patients (Taati et. al., 2019), and smartphone-based conversational agents having inappropriate responses to questions about sexual or domestic violence (Miner, Milstein, & Schueller, 2016).

Lack of attention to middle-years course interventions

This kind of critical thinking about who is included or excluded from engineered products and engineering processes often occurs in design-focused introductory courses or culminating senior capstone experiences. This pattern matches the dearth of engineering education work on "middle-years" courses (Lord & Chen, 2014). For instance, one attempt to address product bias against disabled people has been the incorporation of universal design for product development into undergraduate courses (Blaser, Steele, & Burghstahler, 2015). However, the overwhelming bulk of the literature mentions only first-year courses such as (Gunnarsson, Birch, & Hendricks, 2019), or senior projects such as (Cezeaux, Keyser, Haffner, Kaboray, & Hasenjager, 2008) and (Nasir, Kleinke, & McClelland, 2016). The only mention of anything between the two was in

(Blaser, Steele, & Burghstahler, 2015) with a list of modifications that could *hypothetically* be made to middle-years courses.

Amplifying the challenge, middle-years courses have historically been heavily focused on analytical procedures and technical content (Lord & Chen, 2014). This creates an additional challenge of knowledge transfer. Without explicitly developing inclusion skills in the context of analytical and technical practices, students might consider including diverse users and teammates only in specific contexts - for instance, taking human variability into account during user interviews, but not applying those insights into mathematical models that determine how the actual product is shaped and manufactured. How might instructors integrate inclusive practices into these courses without adding even more material into content-packed classes? This work in progress paper presents an ongoing case study as one attempt to answer that question.

Our setting: transforming a middle-years course at a research-centric institution

Our case study occurs in a required undergraduate course in biomedical engineering at a large public research-intensive university. The course, which we will call *Conservation Principles* for the purposes of this paper, is typically taken in the second or third year and focuses on model-based reasoning and conservation principles (mass, energy, etc.). An NSF grant funded course release time for instructors and support from learning scientists in order to integrate inclusive engineering skills into the course design.

The course redesign team chose to focus on the awareness of bias and its effects on technical modeling. An additional goal was building interpersonal skills at the dyad and team (2-4 people) level, although this second goal is not the focus of this paper. Both goals were incorporated into the formal syllabus and course objectives. The new learning objectives are addressed not in separate lectures about inclusivity, etc. but via changes to the context of the analytical problems being solved. For instance, a modeling problem early in the course focuses on human metabolism, and students are challenged to think about what sorts of bodies might be excluded or excluded from their models (i.e. insulin pump users, pregnant or lactating people, etc.) and the value ranges they typically use for calculations (ex: small children vs. larger adults).

The remainder of this paper describes the interventions that have been developed as part of the ongoing course redesign process. Note that as of this writing (April 2020), the course redesign process has been substantially impacted by the global coronavirus pandemic, as all learning has moved online with little warning, all students have been ordered off campus, and the teaching team is still scrambling to adjust.

Reflective writing prompt: personal experiences with bias

While discussions of bias and limitations in model-based reasoning appear in analytical problems throughout the course, the main intervention took place during an open-ended team project that occurred after the first midterm. As part of the intervention, students were asked to write reflections about their own experiences of bias. They were instructed to choose one of the two following prompts:

1. Please describe a time when you, or someone you know, were personally impacted by bias in an engineering design. What was the value to society the design was intended to create? How did bias affect how the design worked for you (or the person you know)? How did this impact you (or the person you know)?

2. Write a story about when you, or someone you know, or someone you can imagine, were personally impacted by bias in an engineering design.

Student responses were collected and graded based on whether they had been submitted or not. The intent of the reflective questions was to motivate students to examine bias by giving them an opportunity to see how it had shaped their own lives. Students had already been exposed to storytelling as a tool for communication via other initiatives in the department, so we included some reminders from those projects, such as "make it sticky," "include a few compelling details to make the story specific [and] real," and "help the reader see your story, like they are watching a movie."

Intervention phase 1: building a conceptual model of a case study of bias in biomedical engineering

Students were grouped into pairs and asked to write an 800-1000 word case study for an educated but non-technical audience. By this point in time, students were familiar with basic conservation principles (mass, energy, etc.) as well as the dynamics involved in working in pairs and small groups (2-4 students). The requirements were as follows:

1. Identification of an historical incidence of bias in biomedical engineering or biomedicine
2. A description of:
   a. the medical need/problem that the designers were trying to solve
   b. the design that was developed to solve the problem
3. An analysis of how bias impacted the design, leading to shortcomings
4. A figure [of a conceptual model] that graphically illustrates the main aspects of the case.

Students had previously been introduced to conceptual models and had been given prior opportunities to see examples of them, discuss what made for a good conceptual model, and practice creating their own. For the purposes of this class, a conceptual model was taken to be a visual representation of a concept that demonstrates the relationship between its components; its purpose is to illustrate a system and explain it to a reader unfamiliar with the topic.

Additionally, students were required to include citations (in APA format) of peer-reviewed literature supporting the arguments in their case study. We expected students to have some familiarity with finding research sources from prior classes, but also knew this might be a newer skill for most. Consequently, the teaching team provided students with a brief guide reviewing how to search library databases and find relevant literature.

After first-round submissions had been turned in, students were tasked with writing peer reviews of the submissions of other teams. Several reasons were given to them for this, including the opportunity to see more examples of bias and a variety of ways of presenting information, as well as practice with providing helpful feedback to others. Students were given the opportunity to revise and resubmit their conceptual models based on peer feedback.

Intervention phase 2: Proposing a new design/research to create value

The next phase of the intervention was postponed to the summer semester due to the global coronavirus pandemic, so we will describe the planned activity instead. In this phase, each team expands their literature review and proposes recommendations for pursuing future design and research efforts. These proposed efforts should create value in some way for a stakeholder group that is negatively impacted (or not positively impacted) by the current design. Students will write a report quantifying how their proposed improvements could create value for their chosen stakeholder group via changing the dynamics of bias in the situation being modeled.

In contrast to Phase 1, where teams wrote for a non-technical audience, students are told to write this deliverable for a technical audience. This provides an opportunity for instructors to discuss the differences between the two. Deliverables must include a quantitative diagram (sometimes discussed in class as an "engineering diagram") of the design and a model with varying parameters which shows the relationship between the components of the design. These diagrams and models must be used to demonstrate the problematic effect(s) of bias in the older design, as well as the potential positive impact of the new ones proposed. Students will also have reflective writing prompts to complete after creating this deliverable.

Preliminary results

This intervention design is being piloted in Spring 2020 across multiple class sections with a combined total of 91 students. Although the intervention is still in progress and completion has been delayed by the pandemic, we have provided some examples from early-stage student submissions below. These submissions are from a public online gallery of student work created as part of class activities, and have been published with consent from the students whose work is featured.

Results from the written reflection

Students wrote brief stories about a wide variety of ways bias had affected them or someone they knew. Some examples include: (details have been generalized)

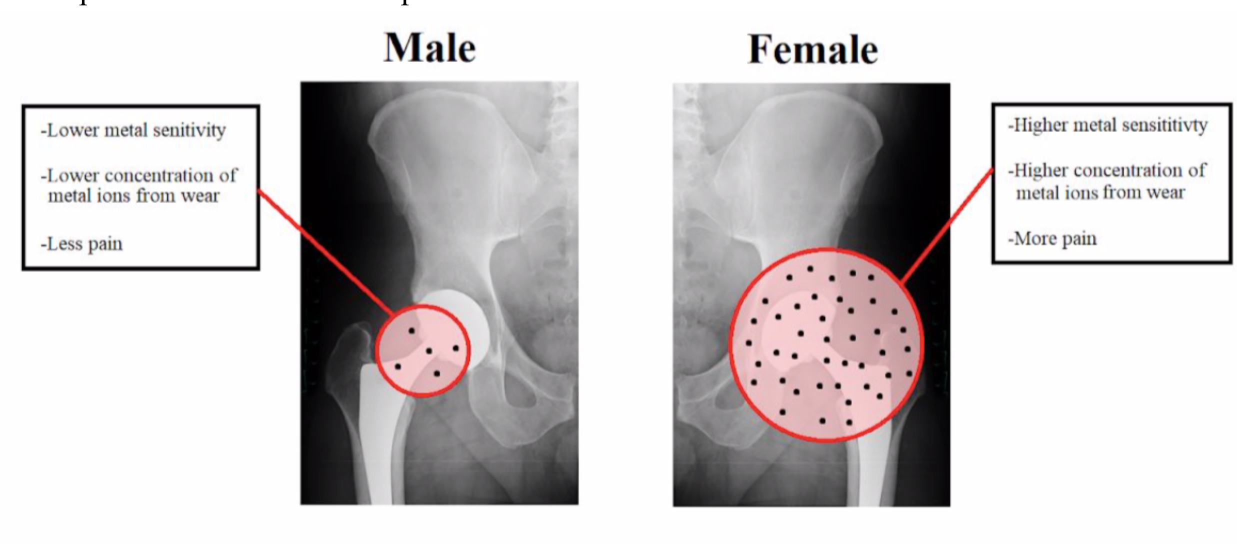
- Having a family member detained by customs and immigration because the automated face recognition system did not work well on members of their ethnic group
- Having an invisible condition that affects part of their body, and being caused unnecessary pain by medical professionals who start routine medical procedures on that part of their body without asking the student if they would prefer a different site
- Seeing a female family member nearly being injured during a medical procedure because the machine had been calibrated for a man's dimensions
- Realizing that a disparity in healthcare training in their resource-poor location had led to a doctor only being trained to recognize melanoma on light-skinned people, which in turn had led to the misdiagnosis and subsequent delay in treatment of a Black patient they had gotten to know
- Watching a family member make sacrifices in order to participate in a clinical trial only to be dropped from it partway through when the trial decided to exclude patients of a certain age

Their stories reflected a wide range of emotions, which we considered to be a positive outcome since we wanted students to consider the affective dimensions of engineering and the impact of technology. Student stories told of disappointment and frustration, unfairness, pain, and wasted time and effort. They pointed at systemic problems by voicing their expectations that similar things would happen again, even if they shouldn't. Some stories included an explanation of what the students wished had happened instead, and the potential impact of design changes (ex: one student explained that people from a particular group might be more confident if they had clothing that properly fit their bodies). Some students also commented that stories like these were the reason biomedical engineers needed to think about the potential of their designs to cause or alleviate these kinds of harm.

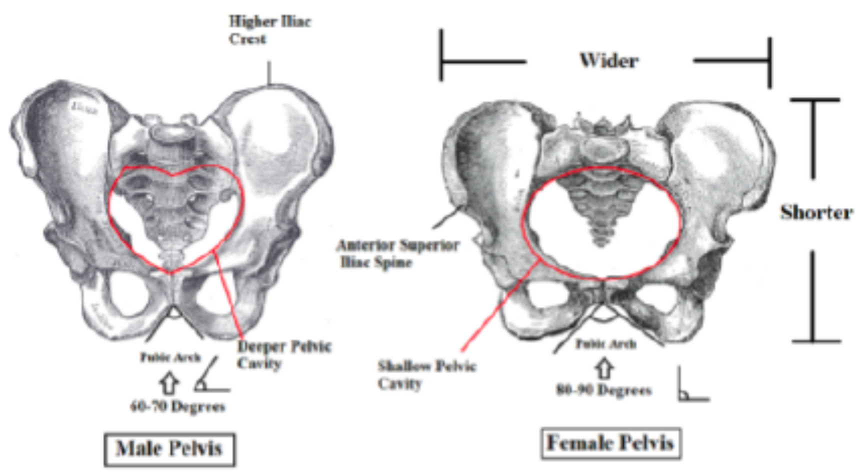
The influence of storytelling training from other department interventions was apparent in the cinematic quality of some of the submissions, such as with this excerpt:

> My father’s left-handed woes began to manifest during early elementary school. Wooden desks, built with an arm support on the right side, never supported his writing arm as it did for all the other children. As his shoulder cramped day after day, teachers would scold him for his sloppy handwriting.“How is it that all your classmates have mastered their cursive letters while you continue to write illegibly?” they scolded.

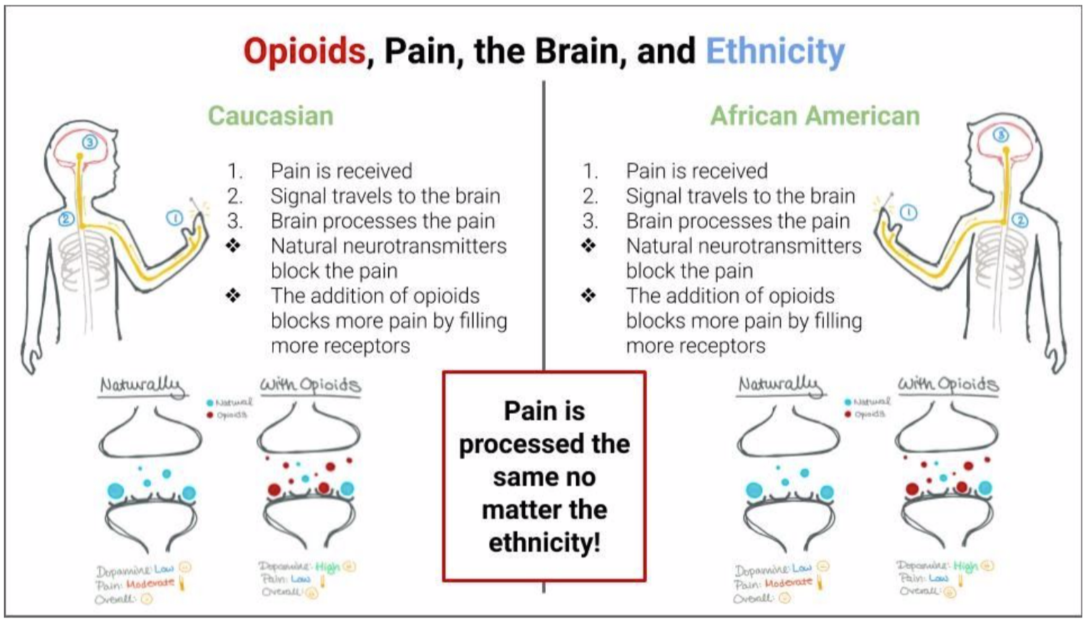
Conceptual model example 1: The image below is an example of a conceptual model submitted by students. This was a comparatively simpler conceptual model that examined gender bias in hip replacement components. The accompanying case study explained how the hip replacements were designed for typical male anatomy, but marketed towards women even if the design could cause potential harm to female patients.



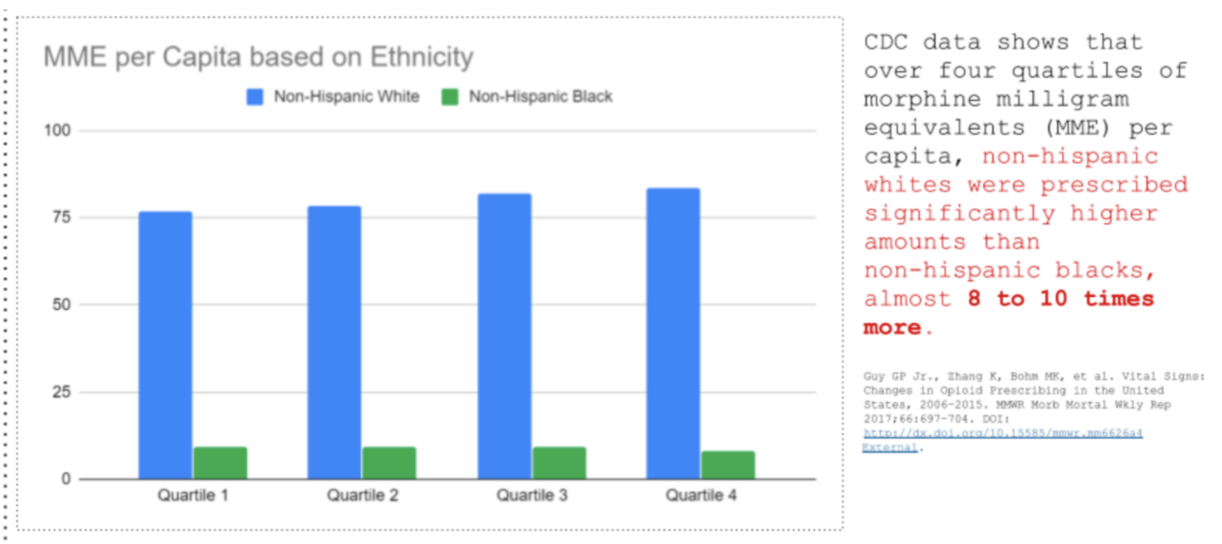
Conceptual model example 2: The below images (next page) show part of another gendered comparison of hip replacements (cropped and slightly rearranged by the authors for legibility in portrait orientation). Note the increased detail in this model as compared to the previous example, which is on the same topic.



Conceptual model example 3: This case study looked into racial disparities with respect to the opioid epidemic, due to misconceptions about African American skin being thicker, nerve endings less sensitive, etc. as compared to Caucasians. In their first submission, these students chose to create a "correct" model that showed the two races as having the same response to pain signals and opioids.



After getting constructive feedback from their peers, this student team added a second section to their model that showed disparities in prescription, after a header that read "the pain processing is exactly the same, and yet…"



Discussion

These results are brief and partial due to the in-progress nature of our work-in-progress paper and the disruption of the pandemic that resulted in an intentional reduction in workload in order to manage student stress. Even so, we can see that students were able to consider bias in their consideration of biomedical designs and the creation of their conceptual models.

We believe that planting seeds regarding bias in models can act as a prophylaxis against technological solutionism (Morozov, 2013), or the belief that technology alone can solve our (often social) problems. By doing this sort of awareness-building of inclusive engineering practices at multiple points throughout the degree pathway, we leave a trail of ideas that other instructors can refer back to in later courses. This was illustrated in reverse by our (and students') abilities to draw from storytelling activities done elsewhere in the department during the written reflections portion of the intervention.

Similarly, even if the Conservation Principles class focuses primarily on analytical content, later courses focused more explicitly on inclusive design can point back to examples from this one ("Remember the project from a year ago where one team looked at the effects of dietary restrictions on intermittent fasting? Let's talk about what sorts of patients might have these kinds of dietary restrictions and why…") With this "spiral curriculum" approach (Bruner, 1960), already used in medical (Harden, 1999) and engineering (ex: Dixon, Clark, & DiBiasio, 2000), the same problems end up doing double duty at different times to address both analytical skill-building and contextual awareness.

Biomedical engineering in particular has been constrained by the cost and scale of existing manufacturing techniques; although the variability of the human body has long been recognized (Tilley & Henry Dreyfuss Associates, 2002), customized equipment and medications have historically been labor-intensive and therefore expensive. With the advent of personalized manufacturing and medicine, the technical limitations prohibiting this kind of work are starting to dissolve. Engineering habits of mind must shift to take this into account, and engineering educators have a role to play in making students aware of historical and existing biases in models and designs so that they do not perpetuate these biases into the future. 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. It is the intentional exclusion of a group of people that something that can and should be avoided, and this awareness is the goal of our case study intervention.

Future work

This work-in-progress paper is only the beginning of an ongoing project. As mentioned previously, this is the first semester of implementation in a course. Some implementation has been deferred to the summer term due to the pandemic. Once the first round of implementation is complete, we will have someone from outside the teaching team conduct interviews with a subset of students from the class to dive deeper into their experiences of this activity and their thoughts about bias in mathematical modeling. Additional plans include developing a separate instrument that will ask students to create conceptual and mathematical models of a situation and look for whether and how they address bias in the model without being prompted to do so.

Subsequent iterations of the course will include the next version of this intervention. Our plans for this are being adapted due to the global pandemic; as of this writing, it is uncertain whether we will be allowed to return to campus to teach the course in-person for Fall 2020. Regardless, we've already received several helpful suggestions for improvement. We have reached out to the writing center to review our reflection prompts and see how we might be able to further hone student communication skills in the next version of this exercise. Additionally, one reviewer suggested introducing the topic of privilege, and having students examine how their various relationships to different kinds of privilege influence their sensitivities to various types of bias. We expect student feedback and interviews after the course is over to further shape our next iteration of the course, and look forward to reporting further results when they are available.

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