Mission Possible: Blending the social and technical through an innovative biodesign challenge module for a Materials Science class

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***Abstract*— This work describes the design, implementation, and evaluation of a module on bioengineering design and material selection in a third-year Materials Science course for undergraduate engineering students in Fall 2017. This module was implemented as part of a larger National Science Foundation REvolutionizing Engineering and Computer Science Departments (RED) project at the University of San Diego, the goal of which is to successfully blend technical content with social context in engineering curricula. This module required student teams to take on missions with specific users and sponsoring agents to design wrist bracing devices, with upfront consideration of social context unique to the mission. Students brainstormed design considerations in class, and then for homework, recommended a material for each of the three missions using technical calculations and engineering design tables that incorporated social context and human elements. Analysis of the weighted considerations showcased student understanding of the financial budgets of sponsoring agents as well as material requirements for specific users and environments. Through this work, students encountered and demonstrated understanding of the close relation between technical and social issues involved in Materials Science.**

Keywords*— *biomedical engineering; design criteria; social responsibility, sociotechnical

I. Introduction

ABET requirements stress the importance of "broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context." [1]. Coursework on these topics can help students begin to see how social context frames their technical work and is, in turn, impacted by the choices they make. Lessons that demonstrate to students how this might be the case can help them become more effective and responsible engineers; however, robust engagements with these themes can be challenging for engineering faculty to integrate into their technically-focused lesson plans.

To address this challenge, engineering educators have explored a variety of strategies. Service learning is an effective pedagogy for achieving these outcomes but is resource intensive so may be difficult to incorporate throughout the curriculum [2 - 5]. Lucena and Leydens have suggested the utility of laying the groundwork for addressing context by incorporating contextual detail into traditional technical questions showing evidence of the relevance of the circumstances in which engineering challenges arise [6, 7]. In Materials Science courses particularly, Baillie and Vanasupa have developed classroom activities to address social conditions in relation to traditional Materials Science topics [8]. Stolk and Martello have tested formal in-class and lab activities that that allow students to engage with humanities [9] and social history of Materials Science and technology [10]. Educators have found that directing student attention to conditions and needs in the context of different nations is particularly useful for integrating attention to social responsibility and the sociotechnical relations inherent in material science into innovative classroom experiences [11 - 13]. We developed an activity where students considered their trash and connected materials characterization to recycling [14].

Bioengineering is inherently interdisciplinary and combines technical and social considerations when applied to humans and the human body. Educators have developed curricula to help students see these connections [15, 16, 17]. At our university, we do not have a bioengineering program but do have a required Engineering Materials Science course for all engineering majors. Since there are materials science considerations in bioengineering, we chose to use a bioengineering context for a design challenge to help students connect technical and social considerations. This also provided an opportunity to introduce our students to the field of bioengineering.

This paper describes the design, implementation, and evaluation of this classroom activity, referred to throughout this paper as a module. This module is part of a larger effort at the University of San Diego's Shiley-Marcos School of Engineering to explicitly address the inseparability of technical content and social context in engineering classrooms as part of reimagining the engineering education canon, undertaken with the support of a National Science Foundation REvolutionizing Engineering and Computer Science Departments (RED) grant [18]. Work toward that ambitious goal is ongoing and includes effort throughout the engineering curriculum [19 - 22]. In this paper we document the pilot-test of a module developed for a third-year Materials Science class including high level

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qualitative assessment of the module's learning objectives. Details of the implementation are provided to assist other educators in incorporating this activity into their classrooms.

II. Module Contexts or "Missions"

We developed a biodesign challenge for engineering students in a Materials Science class where they must consider the design of a wrist brace within different situations as shown in Fig. 1. Our module takes as its focus a simple injury that could happen to nearly anyone anywhere: a broken or sprained wrist. A wrist bracing system can prevent movement to allow for healing. Common wrist braces include several components, one of which is the palmar bracing component that stabilizes and prevents flexion of the injured wrist [see for example 23]. This component is often seen as the functioning bracing component of the wrist bracing system. The material choice for this component may vary considerably depending on social issues including user needs and resources. A critical design criteria for the bracing technology is the ability to withstand forces associated with normal wrist activities (350 N in wrist hyperextension (push-up position)) as well as repeat fracture episodes, where appropriate (2500 N for a healthy adult and 1885 N for an elderly adult) [24, 25, 26]. This makes it an excellent topic for a module demonstrating the relationship between technical work and social context.

An engineer might design a wrist brace in different ways for use by an elderly person in Guatemala, an astronaut, or a soldier on a battlefield. In this module, students became part of "Compadres Consulting", a fictional company taking on missions to design wrist-bracing devices for each of these users. Students were given some context on these missions. They learned that wrist braces for use on Mars are now officially in development with potential mission launch in the next 5-10 years. In addition to other mission goals, NASA must also prepare for common in-flight injuries such as astronaut wrist fracture. Limited shuttle capacity and gravity conditions limit components that NASA can send into space with them to materials that already exist for other purposes on the shuttle. In military use, students were instructed to note that infection occurs in up to 25% of extremity fractures and efficient and sterile treatment can reduce mortality up to 80% [27, 28]. A medic may have only a few seconds to attend to a wounded soldier, but the 2018 proposed Department of Defense (DoD) budget allocates $13.2 billion for science and technology [29]. Finally, with age comes an increased incidence of falls, a common response to which is bracing oneself, often leading to wrist injuries. In Guatemala, one of the poorest countries in Latin America with a Gross Domestic Product (GDP) per capita less than $ 5,000, falls may be related to chronic disease— and associated with limited access to health and social services, low income, little education, and poor housing [30, 31]. A nonprofit developing a wrist brace for users in this situation would be under much different constraints than NASA or the DoD.

The module described in this paper invites students to consider wrist brace design, particularly with respect to material selection, in the context of these users and their sponsoring agencies.

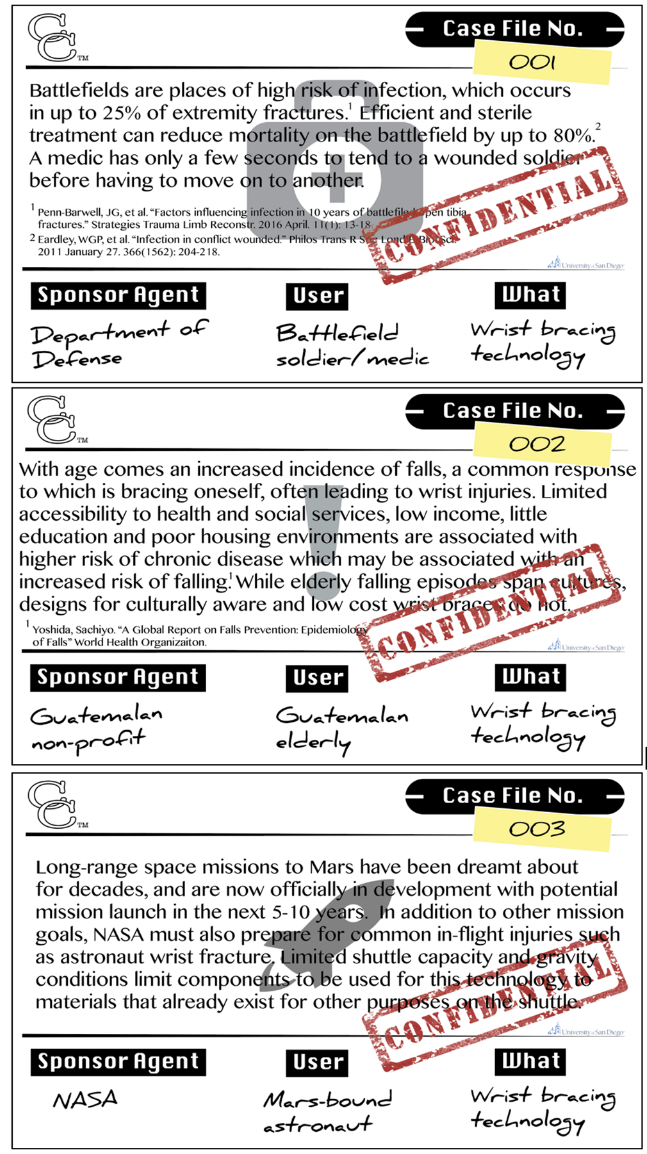

Fig. 1. Mission assignments outlining the general need for a wrist bracing technology for a particular user, the project of which was being funded by a specified ficticious sponsor.

III. Methods

A. Module Design

An interdisciplinary team of educators developed this experiential module for a third-year Engineering Materials Science course. This team included the instructor for the class, a tenured engineering professor with background in Electrical Engineering and Materials Science, and two postdoctoral scholars, one with expertise in Bioengineering and the other in Socio-Cultural Anthropology. All instructors were familiar with active learning techniques and drew upon their familiarity to design and implement the module. This module was developed to guide students through a process of creatively considering social context and the social responsibility of engineers in material choice to complement the technical

Materials Science course content. This module aimed to achieve the following learning objectives:

1. Students will develop a well-constructed, short technical presentation to communicate problem identification, design considerations, and critical questions
2. In choosing a material for a given design, students will consider a range of criteria including technical (e.g. yield strength, density, weight) and social (e.g. cost, user physical ability, age, financial resources)
3. Students will identify and synthesize unique criteria in context

The first learning objective was qualitatively assessed by the educators in-class. The second was quantitatively and qualitatively considered in class and through homework. The third was assessed qualitatively in classroom activities and in the homework. This evaluation is further detailed in the *Assessment Plan*.

Approximately 30 students from Electrical, General, and Mechanical Engineering collaborated with their peers on this module in Fall 2017. The activity was a required part of class. All students were invited to participate in the evaluation of the activity and those who wished to do so, completed an informed consent compliant with university-approved IRB policies.

The module was designed to include several activities, inside and outside the classroom, the duration of which can be seen in Table I.

TABLE I. OVERVIEW OF MODULE ACTIVITIES

55-minute Class Period			**Post-Class HW**
Introduction to Bioengineering (15 min)	Mission Design Consideration Brainstorming Session (20 min)	Prioritization of Considerations and Full Class Discussion (20 min)	Technical Calculations and Critical Evaluation of Design Considerations Associated with Each Mission

The students, none of whom was studying Bioengineering, had little to no previous exposure to the bioengineering field, so a short introduction to the field, where it came from, and why it exists was shared to provide some context for the activity. Following this introduction, facilitators explained the activity to the students as follows: the class now consisted of a new engineering consulting company ("Compadres Consulting") with clients (sponsoring agent) who were asking for help in designing wrist bracing technologies for unique populations. Students were then grouped into six teams and assigned one of the three missions shown in Fig. 1.

Students were instructed to brainstorm as many design considerations as possible given their mission. Basic brainstorming techniques were introduced and supplies were provided to allow for equal participation from each team member. During this brainstorming time, facilitators navigated the room, challenging students to think more creatively, consider the potential users, and evaluate the mission from different angles.

When the allotted time for brainstorming concluded, students were invited to (1) document the number of ideas generated, (2) synthesize and group their ideas with the goal of identifying their top two most unique design considerations for their missions, and (3) identify why these two ideas were selected.

Student teams then had one minute each to share their work with the class, and educators commented on the components of their technical presentation (i.e. problem identification, design considerations, and critical questions). This assisted in fulfilling the first and third learning objectives.

These presentations were followed by a class discussion. Some questions that guided this discussion were: How did you decide as a team what design considerations were most unique? How does "most unique" considerations differ from "most important"? How did designing for the body alter the design considerations? How about the different sponsoring agents? How did your team navigate the ambiguity associated with your design need? What assumptions did you and your team have to make? What did you notice about the other design considerations around the room, for both those missions that were the same as yours as well as those that were different? Areas to specifically highlight included human resources, information architecture/access, literacy, allergies, and ethics. This classroom discussion also facilitated qualitative evaluation of the third learning objective.

Following this classroom discussion, the second segment of the module was initiated: students were assigned a homework problem to choose a material for the splinting (palmar) component of the wrist brace in each of the missions, not just the one they were assigned in class. Background information regarding the size of the component, the forces seen on this component, and properties of materials to consider were provided. First, students were required to calculate the stresses experienced by the palmar component of the wrist bracing system for both normal use and use during a fall (for both healthy and elderly adults). Then, considering these numbers and the material properties provided, students were asked to identify and explain which materials were candidates for further evaluation for use in the bracing system. Students prepared an engineering design table for each of the three missions and further analyzed the remaining materials using designated design criteria (low cost, withstands normal use of wrist, prevents further fracture, compactable, lightweight, and other). Students weighted each of the design criteria and provided justification for their weights as well as the ratings of materials, referring back to their calculations and assumptions they might be making for each mission. Finally, students made material recommendations for each of the mission's wrist bracing systems with specific reference to their rankings, weights, and calculations for justification.

B. Assessment Plan

We designed a number of ways to assess how students were thinking about sociotechnical context of wrist brace design.

These made opportunities for quantitative and qualitative reflections.

In class, students completed a worksheet where they reported 1) the number of design criteria that they were able to brainstorm and 2) listed a few of their favorites. This not only allowed students to reflect on the design criteria that they had brainstormed, but also allows us to compare their output and share examples. Facilitators took extensive notes after the class to capture issues that emerged in a discussion as we led students to reflect on why they might have approached the problem of wrist brace design for different users in different ways.

In the homework problem, students completed a quantitative problem and created an engineering design table indicating how they would weight different issues (both technical and social) when developing wrist braces for each of the three missions.

Reporting quantitative and qualitative data together about this module allows us to produce an account of the pilot experience [32]. Quantitative data allow us to consider how productive student brainstorming was, and with qualitative data generated by observations we can consider aspects of the experience that might be more difficult to count but were nonetheless significant for students. With this information, we can describe in detail how this experience prompted students to think about context and its implications for engineering.

IV. Results and discussion

A. In-Class Activity

The six student teams were divided by mission such that each mission had two teams. Table II summarizes the total number of considerations brainstormed in class for each team and mission.

TABLE II. OVERVIEW OF TOTAL BRAINSTORMED CONSIDERATIONS PER MISSION (TWO TEAMS PER MISSION)

	MISSION		
	Battlefield Soldier	**Guatemalan Elderly**	**Mars-bound Astronaut**
Team 1	22	18	26
Team 2	27	21	14
AVG	*24.5*	*19.5*	*20*

The average considerations brainstormed for all teams was 21.33, while a breakdown by mission shows the students designing for the elderly in Guatemala brainstormed the fewest number of ideas (19.5 average), followed by those designing for the Mars-bound astronaut (20), and finally those designing for the battlefield soldier (24.5).

Worksheets cannot indicate what facilitators saw: that participants seemed energized by the unusual classroom event. Students brought personal experiences to the activity, some of which only came out in discussion. For example, one student, while brainstorming about design criteria for a wrist brace for an elderly person in Guatemala, described how she thought of her grandmother, and came up with several criteria because of that user centered mindset. Other insights into the importance of context came up organically in classroom discussion. Students reflected on how, while cost might be important for the team thinking about Guatemala, it might not present the same kind of constraint to students designing for the DoD. These in-class observations demonstrate achievement of the second and third learning objectives.

One student specifically commented on the power of user-centered design, reflecting that it was much easier to come up with design considerations once he thought about the user and where the brace he was imagining was going to be used. This user-centered approach might be due to students having taken a user-centered design class earlier in the engineering curriculum.

B. Homework

Students worked in eight cooperative learning homework teams of 3-4 students (Teams labeled A-H) to complete the homework. Students were first asked to calculate the stress seen by the palmar component of the wrist bracing system for both normal use and use during a fall (for both healthy and elderly patients). This differed between a healthy and elderly patient because of the variable bone density and resultant force required to fracture the wrist. This concept is among the first times these students were exposed to the human element directly affecting their technical calculations, and therefore indicative of students blending social with technical in the engineering classroom.

Then students were given the following materials to consider for use in the palmar component of the wrist bracing system:

1. Aluminum Alloy 2024 (Heat treated and aged: T3 temper)
2. Graphite Extruded (with the grain direction)
3. Gray Cast Iron Grade G1800
4. Polytetrafluoroethylene (PTFE)
5. Silicone Elastomer
6. Stainless Steel Alloy 304 (Hot finished and annealed)
7. Titanium Alloy ASTM Grade I Annealed

Properties such as Yield Strength, Tensile Strength, Cost, and Density were provided for each candidate material [33].

Then students used their calculations to identify which of the given materials qualified to move forward and be included in engineering design tables. Seven of the eight teams calculated the stresses correctly. Three teams chose candidate materials appropriately with good reasoning. Two teams had a minor error and the remaining three had major errors.

Student teams created three engineering design tables, one for each of the three missions, within which they analyzed the materials identified for further evaluation using the following assigned design criteria, many of which had been brainstormed in class:

1. Low cost
2. Withstands normal use of wrist
3. Prevents further fracture
4. Compactable
5. Lightweight
6. Other (optional)

It was the goal of each engineering table to assist in the final material selection for each of the wrist bracing systems of each mission. Using an engineering design table as part of a design process is not novel, but the process by which these students conducted that analysis was novel. Most of these criteria were supported by technical calculations or provided materials data; however, some of these criteria were heavily influenced by in-class conversations that introduced unique social design considerations not rooted in technical calculation (ex: compactable). Within each table, students determined the weight of each criterion from 0-0.99 (with 0 being low importance and 0.99 being high importance). Tables III-V show the weights assigned to each design criteria within each mission.

The lowest weighted criteria for the Battlefield Soldier mission was "Low cost" with only one team weighing this criterion above 0.5. The highest weighted criteria for this mission was "Withstands normal use" with only two teams weighing this criteria below 0.9, and closely behind as the second highest weighted criteria was "Prevents further fracture". These top two highest weighted criteria (maintains normal use and prevents further fracture) were ranked considerably higher in this mission than any other. This suggests that students felt injured soldiers needed a bracing system that allowed for normal use and prevented further injury more than the elderly in Guatemala or Mars-bound astronauts did.

TABLE III. WEIGHTED DISTRIBUTION FOR SOLDIER MISSION BY TEAM

	Team	Low Cost	Withstands Normal Use	Prevents Further Fracture	Compactible	Lightweight
Battlefield Soldier	*A*	0.1	0.9	0.9	0.5	0.8
	B	0.5	0.9	0.8	0.2	0.4
	C	0.3	0.9	0.9	0.8	0.5
	D	0.15	0.7	0.7	0.8	0.7
	E	0.4	0.8	0.99	0.2	0.6
	F	0.7	0.9	0.8	0.2	0.5
	G	0.4	0.9	0.9	0.8	0.8
	H	0.2	0.9	0.8	0.7	0.3
	AVG	**0.34**	**0.86**	**0.85**	**0.53**	**0.58**
	STDEV	**0.20**	**0.07**	**0.09**	**0.29**	**0.18**

TABLE IV. WEIGHTED DISTRIBUTION FOR ELDERLY MISSION BY TEAM

	Team	Low Cost	Withstands Normal Use	Prevents Further Fracture	Compactible	Lightweight
Guatemalan Elderly	*A*	0.8	0.9	0.8	0.1	0.3
	B	0.9	0.7	0.8	0.2	0.5
	C	0.9	0.7	0.9	0.2	0.8
	D	0.9	0.6	0.6	0.1	0.2
	E	0.99	0.6	0.2	0	0.8
	F	0.9	0.7	0.5	0.3	0.5
	G	0.9	0.8	0.8	0.2	0.2
	H	0.9	0.5	0.5	0.6	0.7
	AVG	**0.90**	**0.69**	**0.64**	**0.21**	**0.50**
	STDEV	**0.05**	**0.12**	**0.23**	**0.18**	**0.25**

TABLE V. WEIGHTED DISTRIBUTION FOR ASTRONAUT MISSION BY TEAM

	Team	Low Cost	Withstands Normal Use	Prevents Further Fracture	Compactible	Lightweight
Mars-bound Astronaut	*A*	0.3	0.9	0.8	0.8	0.8
	B	0.1	0.9	0.8	0.2	0.9
	C	0.7	0.9	0.6	0.9	0.9
	D	0.05	0.8	0.8	0.3	0.9
	E	0	0.8	0.4	0.2	0.99
	F	0.2	0.8	0.8	0.9	0.9
	G	0.2	0.8	0.8	0.9	0.9
	H	0.1	0.7	0.2	0.5	0.9
	AVG	**0.21**	**0.83**	**0.65**	**0.59**	**0.90**
	STDEV	**0.22**	**0.07**	**0.23**	**0.32**	**0.05**

Tied for highest overall weighted criteria between the three missions is "low cost" in Guatemalan Elderly (0.9 average and tied for lowest standard deviation at 0.05). The lowest weighted criteria for the elderly mission was "compactibility" with only two teams weighing this consideration above 0.2. Because cost is a more tangible concept for students in regard to the sponsoring agent's perceived budgets, it is clear that the only mission to be heavily influenced by a need to keep the cost low is that of the non-profit, while the other two (DoD and NASA) do not require as strict a consideration for low cost. This assumption is confirmed in the student descriptions.

Tied for highest overall weighted criteria between the three missions is "lightweight" in the Mars-bound astronaut mission (0.9 average and tied for lowest standard deviation at 0.05). This consideration was also the highest weighted criteria for the Mars-bound astronaut mission with only one team weighing below 0.9. Lowest weighted criteria for this mission was "low cost" with only two teams weighing above 0.2. This can be contrasted directly with the highest category for the non-profit Guatemalan mission but directly agrees with the lowest weighted criteria of the battlefield.

The category with the highest standard deviation and therefore greatest range of weights in all three missions is compactibility for the Mars-bound astronaut. This suggests a lack of knowledge of the amount of space available on the shuttle for this type of equipment, which is a reasonable knowledge gap for these third-year engineering undergraduate students. If this challenge were to be further pursued, students would need access to research areas to better answer this area of design consideration.

Teams were invited to contribute a sixth category for consideration and four of the eight teams did so. These additional areas varied on the sociotechnical spectrum (as indicated in parentheses) and included: conductivity (technical), mobility (sociotechnical), comfort (social), multipurpose use (social), heat capacity (technical), and fatigue stress (technical). Review of additional suggested categories demonstrates that students were considering factors beyond the technical, addressing the unique social contexts of the problems that they were presented with, providing some evidence of achievement of learning objectives 2 and 3.

In the engineering design tables, students were also required to critically evaluate the numbers assigned within each category for the candidate materials. Justification for these ratings and the weights for each mission were provided by the students, encouraging them to blend technical recommendations with reasoning based on social context. Evaluation of these justifications demonstrates that students were able to do so admirably. Sample justifications included:

> *The most important criteria for each mission was considered. The highest for battlefield medic was decided to be compactibility so that it could be transported in the packs. Unfortunately, none of the materials that met the stress specs would be compactible, so compactibility of the brace would need to come from other aspects of the design...The most important criteria for the mars-bound astronaut was being lightweight since it will be sent to space. Function under normal use and during a fall were both highly weighted as well, but a higher weighting was placed on these when lives were on the line and the user would have a hard time getting help if the device were to fail. This is the case for the battlefield medic and the mars-bound astronaut.*
>
> *For the Guatemalan elderly mission...weight was considered as a factor solely in transportation of the brace, and since this isn't something being carried, or sent to space, the transportation isn't very extreme, and so weight isn't that important. However, weight could come into play when considering that a heavy brace would be more burdensome on an elderly person that it would on a fit soldier.*
>
> *For the compactibility and weight factors, a soldier on the battlefield has to carry it around so it must be compact and lightweight, an elderly person in a third world country won't use it if it is a little bulky, and a space mission had to take into account its storage and weight calculate fuel for takeoff and weight balance in the aircraft.*

Finally, students were asked to make a final recommendation of material choice for use in each mission. This was to be supported by the previous work. All teams chose appropriate material choices for the Mars-Bound Astronaut mission (Aluminum or Titanium). Six of the eight teams chose appropriate choices for the Battlefield mission (Aluminum or Stainless Steel). One of two remaining teams chose PTFE (which doesn't meet requirements for withstanding fall) while the other team chose Cast Iron (no data was given on yield strength so use in this application is risky as the material is likely too brittle). Five of the eight teams chose appropriate materials for the Guatemalan Elderly mission (Aluminum or Stainless Steel), while the other three teams chose either Cast Iron or PTFE. Overall, this suggests that students were able to use technical and social criteria in their justification of material recommendations.

One limitation of this work is the level of depth of integrating the technical and social. The technical materials calculations that determined "acceptable" materials were straightforward. However, there was more ambiguity in the students' weighing the design criteria for the acceptable materials with multiple reasonable answers. Combining technical calculations with social considerations in a design table gives students a glimpse into how design decisions may be made in the corporate world, the environment they might find themselves in post-graduation.

This work provides a platform in a required traditional engineering course upon which engineering students can practice blending social context with their technical background. This is not typically the case in engineering courses in the middle years [34]. This is an example of one exercise which engineering educators could incorporate into an existing class to help students begin to develop these skills. Further exercises could build upon this and explore the integration of technical and social in more depth. When considered in the larger context of other efforts throughout the curriculum within our School of Engineering as part of our NSF RED grant, this work contributes to a revolutionary reimagining of the engineering canon.

V. Conclusion

This module invited students to consider social and technical design constraints to ultimately recommend a material of use for wrist bracing technologies in unique environments. For many of these students, this was their first exposure to the field of bioengineering. It is significant that the students responded to designing for the human body (social context) by noting design characteristics of the brace needed because it was to be used on the body (for example: weight of the brace because of elderly or the forces for re-fracture in the elderly varying from those of healthy soldiers and astronauts). This was evident both in-class as well as in their homework.

Because the highest ranked overall categories involved cost for the non-profit and lightweight requirements for the Mars-bound astronaut, it is clear that students understood these design requirements and effectively used them in their design weightings and decisions.

Overall, this module which blended technical content and social context was successfully delivered in a third-year Materials Science class. Achievement of the three learning objectives was demonstrated by student work and instructor observation. Future work will include development of a more modules that blend the technical and social and more robust assessment models for determining module success.

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