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Integrating Humanitarian Values into First Year Engineering Coursework

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Abstract:

Humanitarian values and concerns can be seamlessly integrated into undergraduate engineering coursework, and have proven valuable in enhancing student learning, engagement and retention. We report on initial design and implementation of novel problem-based content for a first year engineering science course. The assignments and exercises involve real world challenges in (a) improving life in a large refugee camp in the Middle East and (b) designing ways to monitor coastal changes driven by climate change, the two exercises being linked through use of an inexpensive Arduino-based device with integrated sensors for projects easily adaptable to remote learning needs (as required by COVID 19 restrictions). These activities are designed to meet course learning objectives in engineering problem solving and value sensitive design. Initial student feedback from this ongoing project, collected via reflections and anonymous surveys, indicate that this is a fruitful approach which clearly enhances student engagement and perceptions of the engineering field. In addition, lessons learned from this work is leading to development of a lecture/workshop in values and humanitarian engineering to be presented in the author's NSF-supported Research Experiences for Undergraduates (REU) Site in Nanotechnology for Health, Energy and the Environment.

Background:

Kevin Passano, in his excellent text "Humanitarian Engineering: Creating Technologies that Help People"[1], defines humanitarian engineering as just that – creating technologies that help people. He also defines it as "creating technology to promote social justice" and also ties it closely to the needs of sustainable development. He goes on to discuss several aspects of social justice, including defining it as "standards for, and a view on how to promote, human dignity, rights, fulfillment for all of humanity." In his later description of the 10 principles of humanitarian engineering, he explicitly calls for the creation of "the best design that meets all constraints (performance, reliability, cost, environmental, social, use of local materials, etc.) in the social and physical context and keeping the people firmly in mind." In fact, all the principles he cites remain focused on one overriding concern – that engineering in general, and specifically humanitarian engineering, requires at its core a focus on people, as stakeholders, clients, impacted communities, and those who should be the beneficiaries of engineering advances (but who all too often may be the victims of engineering done without their needs or the needs of their communities in mind). Just as we extol the virtues of 'student-focused' engineering education, humanitarian engineering should be extoled as 'human-focused' engineering design and development.

These principles call to mind two other approaches to engineering (and engineering education) which share much of the spirit of humanitarian engineering: ABET student learning outcomes and the philosophy of value-sensitive design in engineering.

Several of the current seven ABET student outcomes are very relevant to the current discussion. ABET Student outcome number 2 is "an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors"[2]. This closely parallels the design consideration in the principles of humanitarian engineering defines above. In effect, it codifies the concept that an important 'constraint' to be applied to design is the need to take into account humanitarian principles at the same time as focusing on traditional needs related to performance, reliability, cost, etc. Hence there is a specific requirement to ensure that engineering programs consider humanitarian principles, and have measures in place to assess whether they have done so and whether students understand and can apply these principles in their engineered solutions. Likewise, ABET student outcome number 4 is "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts". Seen through the lens of humanitarian engineering, it is clear that the basis of ethical engineering requires one to consider the impact of engineering solutions with a humanitarian perspective. Indeed, Passano in his 10 principles further calls for the recognition of long-term positive impacts, implementation of life-cycle design, and reducing resource use and pollution, again consistent with ABET's programmatic requirements.

Both the principles of humanitarian engineering and the learning outcomes defined by ABET are further embodied in the philosophy of value-sensitive design (VSD). VSD has been most commonly defined as a "theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process [3]." While methodologies for VSD have been discussed in detail by many authors, as has its usefulness to respond to the need to integrate ethics into engineering design coursework [4], a key consideration in its foundation is that choice is an ineliminable part of engineering design, and that choice is intimately connected with the values of those who are making choices – values based on societal and cultural influences, and hence thoroughly human-focused. The conclusion is that technology is not value-neutral, and values must be considered in deciding what problems to solve, what technology to create, how that technological solution is designed, and what constitutes success in for the designer [5].

In light of this background, it is well recognized that undergraduate engineering programs have for some time expended a significant effort in seeking effective methodologies for incorporation and assessment of content related to ethical engineering and the values of humanitarian engineering into their curricula. Many recent papers have considered methodologies for incorporation engineering ethics, in particular into the first year engineering experience. This can include creation of dedicated courses [6], use of fiction writing as a way to explore ethical implications of technology [7], role playing exercises [8], and many more. The book "Infusing Ethics into the Development of Engineers: Exemplary Education Activities and Programs" made available through the National Academies Press includes many fascinating and useful examples of both stand-alone courses and potential methodologies in this regard [9]. Of course, the deeper question still remains as to the potential differences between "ethical engineering" and "humanitarian engineering". The answer to this question may lay in the argument between subjective and objective nature of humanitarian values or ethics, and how societal and cultural implications may play a role in that definition.

We have attempted during the fall 2020 semester to incorporate humanitarian engineering learning outcomes and associated assignments into course, ESG 100: Introduction to Engineering Science and Design. This first year course is a requirement for the undergraduate major in Engineering Science which I direct, and as such is required to focus on engineering principles and the nature of the design process, and hence humanitarian values is something which must be infused into a framework of existing requirements. The author has been the primary instructor for the introductory course for the past 15 years, but has only recently started to refocus a significant aspect of course content, problem solving and design in such a way as to emphasize humanitarian or value-sensitive issues. It has been a special challenge as well this past semester, as all courses were required to be taught in an online format due to COVID-related restrictions. Hence the material created and implemented is applicable to online course design as well, which may be able to further extend its value. In this paper, content and assignments implemented in the Fall 2020 course offering which have a significant focus on the principles and philosophy of humanitarian engineering are discussed. While this is only a first attempt in many ways, and only limited data is presented, the lessons learned will be helpful in further course design activities to better respond to the critical requirements of learning gains related directly to humanitarian engineering. Further, the lessons learned will be used to develop effective learning strategies and educational content for our REU Site in Nanotechnology for Health, Energy and the Environment, and other coursework.

<u>Research focus and methodology:</u>

Our primary research question is determining whether integrated course content can stimulate student recognition of the role of engineering in responding to humanitarian concerns. In other words, what types of integrated content and assignments may be able to best impact student perceptions (while meeting student course learning outcomes). These learning outcomes are:

- Demonstrate an ability to apply technical tools and knowledge to practical systems and problem solving
- Design, understand, build, or analyze selected aspects of the human-made world.

- Understand how engineers and engineering play key roles in solving problems facing society.
- Understand the requirements of the Engineering Science program
- Understand the important factors for becoming a successful professional engineer
- Understand the evolution and principles of modern manufacturing
- Learn how engineers use mathematical relations, physical laws, standards, and a logical, informed approach to formulate and solve engineering problems
- Learn how engineers collect, interpret and present data
- Understand how ethics and value sensitive design play a role in engineering problem solving

In order to collect and present data on the impact of the course assignments, I chose to use reflections prepared by students as part of each course assignment, in which they are asked to discuss what about the assignment most surprised or interested them, and how they feel the assignment relates to other coursework as well as engineering in general. In addition, I used a post-course anonymous survey to collect student opinions about which assignments they felt were most closely aligned with ABET outcomes as well as value-focused engineering, civic engagement and humanitarian principles. The post course survey requested students to identify which specific assignments they felt best met the following objectives:

- Most valuable assignment questions for learning of engineering principles
- Most valuable assignment questions for real-world problem solving
- Most valuable assignment questions for understanding humanitarian concerns and civic responsibilities of engineers

In addition, a short essay format response was provided for students to describe which of the assignments they felt responded to any of the ABET 1-7 student learning objectives. This allowed students to also address, if they felt it appropriate, whether any assignments specifically related to either "an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors" or "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts", both of which relate to humanitarian engineering. Of the 24 students in the class, 18 provided responses (though only 9 responded to the final question relating course assignments to ABET learning outcomes). The low response rate is likely due to a problem in making the survey visible (which led to delays). The survey will be revised (to better analyze student perceptions) and presented appropriately for data collection in future course offerings.

Course structure:

The online lectures were presented to the class via Zoom, as were weekly 'office hours', during which students could enter the online space to type or speak questions. The course used lectures and readings (most of which were fairly traditional, using supplemental materials in addition to "Engineering Your Future: A Brief Introduction to Engineering" by W.C. Oakes and L.L. Leone

[10]) to explain the general role of engineers and introduce certain engineering principles. To align the course with the program for which it is an introductory requirement, extra readings were provided on materials engineering. To provide a hands-on tool for the class, which all students could easily obtain and on which a number of assignments could be based, I chose the Circuit Playground Express (CPE), an Arduino-based device from Adafruit [11]. This was especially useful, as the device includes a number of excellent sensors (accelerometer, light sensor, microphone, temperature sensor, voltage input and output, and capacitive touch pads), has excellent software support for learning both simple block programming (Makecode) and a version of Python, and is quite inexpensive. Software support on the Adafruit website also includes many user-contributed programs and projects, as well as learning support for data logging. The CPE was used to teach electronics, simple programming, data collection and data presentation, design of experiments, and as the basis of a final design project. As noted below, this made it ideal to create some humanitarian-focused assignments.

As the focus of this study involves the assignments (which were assigned, collected and assessed via the Blackboard course management platform), these are briefly summarized in Table 1 below. While most of the assignments are fairly self-explanatory, several specifically designed to introduce humanitarian engineering elements to the course will be discussed below. The facemask efficiency calculation assignment (D) is fairly straightforward. However, it was felt that students' personal experiences would expand their view of the role of engineering and especially the critical role of engineers in responding to the COVID needs for personal protective equipment (PPE). It was hoped that this would be potentially make this assignment more personally relatable and hence invite the students to consider the societal impact of engineering design. In addition, many students were aware of the role their fellow students were playing in helping to create PPE in the current pandemic emergency.

We were very fortunate during the Fall 2020 semester to have a Zoom lecture from Dr. Anthony Ryan from the University of Sheffield. Dr. Ryan had been involved in applying the techniques of engineering problem solving to the production of food in the Za'atari refugee camp, in Jordan, one of the largest refugee camps in the world with a population of over 80,000 mostly Syrian refugees who were displaced by armed conflict [12-13]. Invited with others by the office of the United Nations High Commissioner for Refugees (UNHCR), he sought a way to help the refugees, many of who were farmers, grow food in the camp where the soil is dry and unsuitable.

In addition to providing food, the hydroponic farming created a sense of human dignity for the people of the camp, and brought renewed purpose to their lives in many cases. His inspiring story (which is also the subject of a documentary as well as his lecture – both of which were made available to the class) focused on the use of recycled polyurethane mattresses to form hydroponic gardens. The work was immensely inspiring, and it was felt that Dr. Ryan's story –

Table 1: Assignments for Introduction to Engineering Science and Design (Fall 2020). Assignments added to specifically provide additional humanitarian content in bold.

Assignment	Engineering principles	Humanitarian element(s)	Value-related concepts	Assessment method
A. Talking with/interviewing a practicing engineer	The role of engineers and engineering education (for non-engineering careers)	None specifically in the assignment description	Career choices	Essay description of interview/ conversation
B. Describing history of manufacturing and how it has changed	Manufacturing engineering; design for manufacturing; history of engineering	Environmental impact and the changing workplace briefly discussed	Economic choices	Essay comparing manufacturing over time in a specific area
C. Assignment to analyze materials and design of particular campus structures	Material properties, research skills, design aspects, mathematical estimating	None specifically in the assignment description	Choices related to purpose of structures, values reflected in design	Calculations and essay
D. Assignment about efficiency of facemasks	**Engineering principles (fluid dynamics, permeability, etc.)**	**Availability of PPE in a pandemic, societal impact**	**Impact of news and perceptions on values**	**Calculations and essay**
E. Question on estimating your electricity usage	Calculating and estimating energy usage	None specifically in the assignment description	Energy use and conservation	Calculations and essay
F. Setting up and testing CPE	Electronics, sensors, micro-processors, simple programming	None specifically in the assignment description	None specifically in the assignment description	Essay, including some data, images
G. Experiments with using CPE for soil moisture and data logging	Experimental design and data logging. Data presentation, statistics related to data	Brief commentary in related lecture on climate change	None specifically in the assignment description	Data and graphs
H. Relating experiments to Dr. Ryan's work with the Za'atari refugee camp, design of experiments	**(details below) Hydroponics, environmental engineering, experimental design, materials, data collection**	**Lecture and materials on humanitarian challenges in refugee camps; human dignity**	**Feeding refugees, helping politically and economically disadvantaged set up a support system**	Essay, data and graphs
I. Watching senior design presentations (Zoom) and critiquing them	Engineering design process; standards; materials issues	Some designs included clean water environmental protection	Sustainability (in most designs)	Essays (critiques of presentations).
J. Final design using CPE to monitor for coastal changes from climate change	**Engineering design; sensors; CAD**	**Climate change, impact on coastal communities discussed**	**Sustainability, coastal design in response to climate change**	**Design report.**

both from a materials engineering and humanitarian perspective – would make an ideal focus of an assignment for the class. The students were able to attend the Zoom lecture – one of the benefits of the online environment -- ask questions, and consider what it means to be a humanitarian engineer in a truly challenging environment. The assignment itself asked students to apply what they had learned about using their Arduino/sensor device and experimental design to testing of sponge materials for hydroponics and detection of salt in water (also a problem in the refugee camp) and how that could be applied to the engineering tasks discussed by Dr. Ryan, as well as similar situations in the world.

The final assignment, a design project to use the Circuit Playground Express (CPE) as the basis of monitoring coastal sea level change, leveraged the work being done in our local area on climate-induced coastal changes along the Long Island Sound. They were directed to websites and a report prepared by the EPA concerning monitoring sea level changes for the Long Island Sound Study [14]. Students were directed to consider climate change impacts as part of the background for their design report, and were directed to use this as source material for the design project.

Results and discussion:

For the post-course survey, students were asked to identify which assignments were most valuable in addressing each of the following three areas: (1) Most valuable assignment questions for learning of engineering principles; (2) Most valuable assignment questions for real-world problem solving; and (3) Most valuable assignment questions for understanding civic and humanitarian responsibilities of engineers. They were also asked to give some short answers to comment on whether they felt specific assignments responded to any of the ABET student outcomes. For the purpose of this paper, I will only focus on the responses related to humanitarian engineering as we have defined it. 18 of the 24 students in the class responded to the survey, and their answers were both surprising and not surprising:

a. 67% (12 out of 18) of respondents identified the refugee camp/hydroponic assignment as clearly reflecting the civic/humanitarian responsibilities of engineers.

b. More surprisingly the only other assignment that more than 50% of the respondents cited as reflecting humanitarian or civic engagement was “A. Talking with/interviewing a practicing engineer”, which was cited by 100% of the respondents as relevant to learning about civic/humanitarian responsibilities.

c. All other assignments were only chosen by 0 to 33% respondents as valuable for understanding civic/humanitarian responsibilities, including the final design assignment (J) which was cited by 33% of respondents.

d. The assignments most cited as valuable assignment questions for real-world problem solving were the assignment on hydroponics in the refugee camp, and the final design assignment related to climate change (both chosen by 83% of respondents).

While it was expected that the assignments related to refugee camps and climate change would be able to motivate students to see humanitarian values in engineering, and also help students to see the value of real-world problem solving, it was surprising that a ‘recycled’ assignment -- the discussions with an engineer or someone who had an engineering background -- was cited so often as helping students to understand the civic/humanitarian responsibilities of engineers. Student reflections provide some insight.

While comments made by students on their experience in considering the role of engineering problem solving for the refugee camp focus on the comments and passion of Dr. Ryan as having made an impact on them, quite a few mention that their conversation with a practicing engineer or someone who had been educated as an engineer (most often a family member or friend) resulted in some level of discussion of the importance of engineering in solving world problems (and it is likely that students who were most successful in reaching out to an engineer were more likely to respond to the survey as they were more engaged in the class). So in light of this, it is not surprising that this conversation remained fresh in their memories and hence that it helped to demonstrate positive values and the humanitarian role of engineering.

This is also strong evidence that it is likely that exposure to role models – professional engineers who are actively involved in some way in humanitarian engineering, or at least those who see its importance – is a key to effective integration of learning outcomes on humanitarian engineering into undergraduate engineering education. This also may be related, in a sense, to Edgar Dale’s well known “Cone of Learning” [15], which in many ways may also be correlated to the pedagogical concept of active learning. Reading about humanitarian engineering may be valuable, as is watching a video or documentary, in promoting humanitarian engineering learning. However, in moving to the active learning portion of Dale’s Cone of Learning, the greater retention of learning (and likely student engagement) occurs as we create a personal, active environment in which students can interact with practicing engineers – and this is equally relevant to an online environment. Students who attend a live Zoom lecture in which questions are asked and in which they can see the emotional and very human response of the speaker and the passion in their work, or students who have a one-on-one conversation with a practicing engineer (who in many cases is a close friend or family member) have a stronger response and experience a greater impact from the material. This is also the reasoning behind the urgency to return students to the lab and classroom from purely virtual learning environments. However, even within the limitations imposed by a virtual learning environment, this may signal an effective way to integrate value-based, ethical and humanitarian engineering into coursework.

This hypothesis will be further explored via expanding synchronous presentations and workshops with professional scientists and engineers involved in real-world humanitarian challenges as part of our ongoing REU site to emphasize the importance of humanitarian concerns in engineering and scientific research. We will be reaching out to engineers involved in emergency PPE development as well as several engineers designing low cost emergency housing and other technology to assist the homeless. The latter has been cited as an especially critical humanitarian issue impacting over half a million people in the US alone, and has become the focus of a number of humanitarian engineering efforts [16].

Summary

While minimal data from surveys and reflections was generated so far, it was sufficient to suggest that integration of real-world engineering challenges with clear aspects of value-based, ethical and humanitarian engineering into problem-based coursework can enhance first year student learning outcomes. However, it is most effective, even within a virtual learning environment, to ensure that students can have a personal, real-time interaction with engineers who can inspire them and encourage their appreciation of humanitarian concerns and goals in engineering design and problem solving. Expanding data collection to enhance research methodology will be implemented for both future course offerings (Fall 2021) and to assess the impact of speakers presenting humanitarian engineering in our summer research program.

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