Knowing and Caring about Sanitation

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NOTE: this paper has co-authors.

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Abstract

This paper describes the second half of a first-year course designed by an interdisciplinary team of faculty from engineering, humanities, social science, and entrepreneurship and innovation. Our course, "Humanitarian Engineering Past & Present," begins with a nineteenth-century sewerage problem before turning to current-day problems of sanitation. Having studied in depth the challenges of providing acceptable sanitation to an ethnically, economically, and topographically diverse community in a nineteenth century industrial city, long before sanitation was considered a basic human right, students form teams to identify and propose a solution to a sanitation problem in some particular part of the contemporary world.

This paper discusses our classroom activities and the learning outcomes they produce, primarily around the ethically infused subject of sanitation, why it is a basic human right included in the United Nation's Sustainable Development Goals, and why engineering students should be curious about how people live in parts of the world where sanitation has not yet been secured for all people. Our project aims to understand how students are motivated first to care about the UN Sustainable Development Goals, and then to develop the expertise to be able to help meet these goals.

Introduction

"Humanitarian Engineering Past and Present" is an experimental first-year, two-course sequence designed and taught by an interdisciplinary team of faculty from engineering, humanities, and entrepreneurship and innovation at Worcester Polytechnic Institute (WPI), a technology-focused university in Worcester, Massachusetts. The university is best known for its 47 year-old project-based curriculum. WPI's 14-week semesters are divided into two seven-week "terms." Our sequence involves a three-credit course in the first term (for which students receive Humanities and Arts credit) followed by another 3-credit course in the second term (for which they receive Engineering credit). The two courses are an integrated six-credit hour sequence.

"Humanitarian Engineering Past and Present" provides a deep, integrative learning experience of benefit to both STEM and non-STEM students, and it is our hope that it will be taught in liberal arts as well as technical institutions. The course brings together content, disciplinary approaches, and pedagogy from both the humanities and engineering disciplines, and most classes and homework assignments are informed by transdisciplinary thinking, including conversations about how a humanist or an engineer might think differently about a problem. Our goal is to train a new generation of young professionals who are well versed in both the technical and the human aspects of engineering and who have the capacity and inclination to help improve society.

Our course is aimed at appealing to underrepresented populations in STEM, who tend to be highly motivated by the prospect of helping real communities with real needs (Kuh, 2008). The class was developed and is taught by a multidisciplinary team from engineering and liberal studies. Problems located within the discipline of civil engineering (and closely related engineering disciplines) are the technical focus of our work to teach about sanitation projects, and yet we recognize that engineering is only a fraction of the solution: situational suitability and culturally appropriate approaches are equally important.

The two-course sequence, "Humanitarian Engineering Past & Present," begins with a nineteenth-century sewerage problem (during the first half of the semester) before turning to current-day problems of sanitation. Having studied in depth the challenges of providing acceptable sanitation to an ethnically, economically, and topographically diverse community in a nineteenth century industrial city long before sanitation was considered a basic human right, students learn to identify and propose a solution to a sanitation problem in some particular part of the contemporary world.

In this second half of the semester, students work together in teams to consider and evaluate social, financial and environmental tradeoffs before identifying and designing engineering solutions to water and sanitation problems in a specific place in the developing world. (Our most recent group of students chose project sites in Varanasi, India; South Tarawa, Kiribati; Rocinha, Brazil; Port Moresby, Papua New Guinea and Kalena Rongo, Indonesia.)

Sanitation in the Developing World

We chose the broad theme of sanitation in the developing world because we wanted to challenge students to make the connection between historical and contemporary problems. Those associations were clearest in marginalized communities where infrastructure and services have not yet caught up with our global understanding of basic human rights; in many ways, the problems experienced by these communities are the same problems facing industrializing communities in the nineteenth century, including the industrial New England city our class considered during the first half of the semester. Furthermore, we did not want students to focus on problems and projects with highly technical solutions and sufficient resources to address those problems. We felt that those technological and financial advantages would obscure the importance of understanding human needs and conditions and, importantly, integrating these human elements into engineered solutions.

Humanitarian Engineering Defined

The term "humanitarian engineering" is often used in reference to responses to human and natural disasters: conflict zones, refugee crises, earthquakes, floods, and so on. In these emergency situations, the humanitarian engineering response requires the rapid installation of infrastructure such as basic shelter, sanitation, water and medical delivery and other emergency services. Our broader view of humanitarian engineering includes engineering in the service of communities on the margins, without consistent access to basic human rights like food, water, sanitation, and gender equality. In this context, we view engineering as a social service and social practice, where the tools, methods and resources (of civil, mechanical, chemical, electrical and other engineering disciplines) are harnessed for the betterment of society. Our thinking aligns with the orientation of a growing number of programs in humanitarian engineering, like those found at the

Colorado School of Mines, Southern Methodist University, Pennsylvania State University, and the University of Colorado at Boulder.

In our course, "Humanitarian Engineering Past and Present," engineering, entrepreneurship, social science and the humanities converge to promote solutions that are culturally appropriate, feasible and sustainable. We aim to teach students that the most effective and socially responsible practices combine content, approaches, and dispositions from both the humanities and engineering, so they can navigate their way through the integrated space of these disciplines. Now in its second iteration, the course offers students opportunities to reflect on social justice and ethical issues while developing the qualities of compassion, empathy, and curiosity.

Background and Context

Sanitation is a Human Right

Inevitably, students and professionals must navigate the ethical labyrinth of imperfect options and make difficult human and design decisions. In "Humanitarian Engineering Past and Present," students are supported in their ethical decision-making by the knowledge that while sanitation is a basic human right, billions of people are currently deprived of that right.

An estimated 30% of the world's population – approximately 2.5 billion people – does not have access to basic sanitation services. Fewer than one in every three people in Sub-Saharan Africa have access to a proper toilet, and one billion people around the world currently defecate in the open (United Nations). Nearly 80% of illnesses in the developing world are linked to poor water and sanitation, and an estimated 1,000 children die every day from preventable water and sanitation-related diarrheal diseases (ibid).

The environmental and economic costs are staggering, as are the costs to personal dignity. The absence of toilets leads to open defecation. Inferior facilities fall into disuse. Unsafe facilities incite abuse, and untreated wastewater and fecal sludge leads to disease. The United Nations Sustainable Development Goals (SDGs) were developed to address the needs of those left out of the sanitation revolution by heightening awareness and allocating funding to provide assistance and alleviate suffering (United Nations, 2016a). The Sustainable Development Goal most pertinent to our class is Goal #6, to "ensure availability and sustainable management of water and sanitation for all" (United Nations, 2016b). As the United Nations notes, "Water and sanitation are at the very core of sustainable development, critical to the survival of people and the planet" (ibid).

Goal # 5, to "achieve gender equality and empower all women and girls" (United Nations, 2016c), is also pertinent. "Gender equality remains a persistent challenge for countries worldwide and the lack of such equality is a major obstacle to sustainable development" (ibid). As is too often the case, women and men are afforded unequal access to sanitation facilities, exacerbating disparities in health, access to education and other opportunities.

Theoretical Frameworks

Responsive Design
We challenged our students to take a human-centered approach to sanitation in order to improve lives and livelihoods. Contextual inquiry and human- and user-centered design provide the most applicable models and theoretical considerations, given their necessity to successful development outcomes (Dodson, 2014; Ho et al., 2009).

Contextual Inquiry and Considerations of Use
Contextual inquiry involves a determination of users' needs in the context of their particular place, time, opportunities and constraints (i.e., low-resourced rural community members, or residents in informal settlements in high-density urban areas). In "Humanitarian Engineering: Past and Present," we used the principles of contextual inquiry to introduce students to the concept of creating a "thick" description of a people and a place (Geertz, 1973), albeit without conducting fieldwork. This knowledge – and empathy – informed student sanitation system designs. The 'considerations of use' framework captures the broad characteristics of a user population, spanning financial, physical, environmental, mental and educational contexts (Lalji & Good, 2008). This framework helped guide our humanitarian engineering students toward an appreciation of the complexities of social systems.

Human-centered Design (HCD)
Contextual design proceeds from contextual inquiry. As students intensify their understanding of community geographies, economies and social realities, they fuse this understanding with human and user-centered design methods (Cardella et al., 2012; Chipchase, 2006; Maunder, Marsden, Gruijters and Blake. 2008; Winschiers-Theophilus, et al., 2010). Human-centered design (HCD) principles guide the student and practitioner to keep the user and the user's requirements at the forefront of the design process. Human-centered design in a *developing-world* context calls on system designers to meet unique user needs while simultaneously addressing difficult infrastructure contexts in communities on the margins (Dodson, 2014; Marsden, 2008). HCD for development encourages designs that address the needs or aspirations of people in developing regions, or designs that address specific social, cultural, and/or infrastructural challenges of developing regions (Ho et al. 2009).

User-Centered Design (UCD)
Similarly, user-centered design (UCD) considers a user's broad and complex social, cultural, and physical environment to inform design requirements, models, prototypes and testing phases. UCD-inspired designs consider the unique circumstances of use in under-resourced communities by often-marginalized or low-skilled users (Ho et al. 2009). While training students in HCD and UCE, we also reminded them to keep in mind the merits of pragmatic design, which "requires no radical alterations to the existing ecology and can lead to many viable solutions" (Marsden, 2008). In this course, student teams incorporated human-centric knowledge into designs and models of composting toilets suited to the community, as well as water treatment and wastewater conveyance systems in the developing world.

Sampling and Participants

This course ran twice as an experimental class (first in spring 2016 and then in fall 2016) for which a mix of first-through fourth-year students received humanities and engineering credit. Our sample consists of 12 students (mixed years) in the spring offering and 17 students (all first-year) in the fall version of the class. The spring offering was 40% female and 40% non-white, while the fall offering was 30% female and 35% non-white. In the first case, class demographics for under-represented minorities were slightly higher than for the WPI campus (with a 33.3% female undergraduate population and a 37% nonwhite undergraduate population), while in the second case they nearly matched the general population.

The authors are aware of the limitations of the small sample size, but consider their findings and assessment of empathy, ethics and social justice learning outcomes to be sufficiently noteworthy to warrant sharing with the engineering education community.

Data Collection Methods

We used an online learning management system (Canvas) to collect individual and team assignments and student reflection essays, which we assessed for direct learning outcomes. End-of-term team posters provided data on integrative learning. Where relevant, faculty notes from in-class discussions and activities were used to assess the course and student learning, as were numerous evaluation methods, described in the Assessment section.

Approach

This paper discusses our classroom activities and the learning outcomes they produce, primarily around the ethically infused subject of sanitation, why it is a basic human right included in the United Nation's Sustainable Development Goals, and why engineering students should be curious about how people live in parts of the world where this human right has not yet been secured for all people.

We embraced active, embodied learning through labs, assignments and activities aimed at educating students about ways to isolate people from human feces; prevent nuisance organisms from contacting excreta and transmitting disease; inactivate pathogens; and prevent excreta from entering the human environment.

Engineering Content and the Social Context

We chose wastewater treatment as our engineering focus for several reasons. First, it introduced students to the historical evolution of this important technology and involved them in sanitation issues in the developing world. Both aspects address UN Sustainability goals and are consistent with engaging under-represented minorities in STEM content. Furthermore, the wastewater treatment process itself allows the introduction of several introductory engineering topics that are appropriate for first-year students and applicable to nearly all engineering and science majors, not just limited to civil engineering. These include conservation of mass and energy, materials selection, fluid flow, and process/product design. We were also able to introduce relatively straightforward laboratory experiments and a field trip consistent with experiential learning. Examples of some of the learning modules are shown in Table 1 below with details provided in the subsequent text.

Table 1: Examples of "Humanitarian Engineering Past & Present" modules related to sanitation in the developing world.

Module Name	**Module Type**
Waste Treatment Process Units	Lab
Mass Balance	"Gamified" Lab
Fluid Flow	Lab
Wastewater Treatment Facility	Field trip
Love Canal	Movie and discussion
Problem Statement	Lecture and team work
Stakeholder Analysis	Individual and team work
Gender Analysis	Individual and team work and activity

Module: Waste Treatment Process Units

Civil/environmental (CEE) and chemical engineering (ChE) professors introduced the integrated process of waste treatment with attention to individual process units and their operation. This stage of the course was opportune for a lab exercise. The CEE instructor conducted a lab introducing students to wastewater samples from a local wastewater treatment facility, along with basic methods to characterize wastewater. The class discussed the nineteenth-century methods of characterizing wastewater (e.g. color, visual turbidity, solids, etc.) then, using an Imhoff cone, measured organic content, turbidity, suspended solids, and readily settleable solids. Students measured the pH of the wastewater initially, and then again after the professor added acid to replicate the discharge of various industrial wastes associated with tanneries, metal-works, and other industries. The students became aware of variations of the subjective characterizations (such as color and visual turbidity), and how repeated measurements of identical samples could produce different numbers (turbidity, suspended solids). Basic statistics (e.g. average, standard deviation) were used to characterize this real data collected in the lab.

Module: Mass Balance

That module was followed by one presented by the ChE instructor who introduced basic mass balances with specific applications in sewage technology. For instance, we designed a lab aimed at teaching the principles of basic filtration, a common step in wastewater treatment. Students simulated nineteenth-century devices and materials to study basic solids filtration. The ChE faculty member "gamified" that filtration lab, challenging teams to create a filter that was most effective at removing coffee grounds suspended in solution. Using different materials, teams replicated a commonly used method for water and wastewater treatment. While learning about various operating variables and cost trade-offs that affect the filtration process, students also learned about historical water filtration systems and best practices of the time. Because similar technologies are appropriate in some modern-day developing world sanitation contexts, this module helped students make the intellectual connection between the past and the present. An example of the lab activity is illustrated in Figure 1.

Figure 1: Students testing simulated sewage using technology similar to that used in the 19th century.

Module: Fluid Flow
A third lab experience, developed by our biomedical engineering (BME) instructor, taught the principles of fluid flow. Many sanitation and water applications involve gravity flow of fluids, typically from storage tanks. In this lab, students studied the effects of height (pressure drop), pipe size, friction loss (pipe length and pipe type) and fluid properties on flow rate. To observe these effects, each team was given a large reservoir, fluids of different viscosity and density (water, glycerol, and vegetable oil), and copper pipe and plastic tubing of various diameters and lengths. Using these variables and the varying height of the reservoir above the discharge point, they set up controlled experiments to measure flow rate as a function of these independent variables. Then data from all six teams was combined for analysis using Bernoulli's equation.

Module: Wastewater Treatment Facility
A field trip to the Upper Blackstone Wastewater Treatment Facility further reinforced the relationship among engineering principles, integrated process operation, and capacity expansion. Led by treatment facility personnel and the CEE instructor, this tour included the plant and its quality control lab. The state-of-the-art facility serves 14 communities and more than 250,000 people. Students directly observed the applications of what they had learned in labs, lectures, and readings: fluid transport, energy conservation, mass conservation (including bioreactions), and overall operations. They also saw how the individual treatment steps work together in the treatment facility to produce modifications to water quality parameters such as those discussed in the earlier lab. Seeing the discharge of the treated wastewater to the receiving stream, students understood the ramifications of discharging deleterious constituents to the environment

that could come into contact with people and wildlife. This large-scale operation gave students a new appreciation for the importance of engineering in sanitation, as evidenced by some of our assessment data shown below.

Other faculty facilitated additional class sessions on the basics of material properties and their selection, energy balances in the drying of fecal matter, and the principles of engineering design. These sessions included traditional lecture with in-class problem solving, hands-on team exercises, and homework. Materials content was provided by our Innovation and Entrepreneurship (I&E) instructor; the mechanical engineering (ME) instructor provided energy modules; and BME and Humanities faculty led the design instruction. This multi-instructor approach was not only necessary due to the expertise needed, but it also reinforced the reality that real-world problem solving requires multiple talents.

Module: Love Canal

Congruent with course objectives to tether ethics and engineering, we incorporated a module on the Love Canal hazardous waste dump. The students were required to watch a video ("The Poisoned Dream: the Love Canal Nightmare") before class, and answer questions on the video with a homework assignment. Subsequently, the instructor led a class discussion analyzing the environmental and human health disaster. This discussion illuminated human health issues and clarified the causes that led to the pollution and suffering. Through these discussions, the students were able to see the degree of suffering, and the difficulty in finding a technically acceptable and affordable solution. The students considered how missed opportunities to take action by the different stakeholders involved (businesses, residents, developers, architects, politicians, scientists) may have prevented the environmental and human health catastrophe, and/or aided in the development of a solution. This transitioned into a lively discussion on the ethical responsibilities of those involved. All student teams were able to identify specific ethical deficiencies that contributed to Love Canal, which they were able to defend to the class. It became apparent to the students that real failures such as Love Canal were "messy," harmful to humans, and difficult to resolve.

Module: Problem Statement

Throughout the course, we held paramount the requirement that students understand the community context *before* designing any sanitation interventions. To that end, faculty engineers and non-engineers helped students to first define a problem before pursuing a solution – an often-difficult task for engineering students who might be compelled to rush to the design phase prior to a careful consideration of context, customer and culture.

We guided students in developing a problem statement prior to beginning work on any designed solution. This included a statement that described the problem their team sought to address and provided an explanation and data demonstrating a) *what the problem is* (i.e., how do we know it exists in the place you are studying?) What peer-reviewed sources and credible news accounts give evidence of this problem); b) the *impacts of the problem*; c) the *cause or causes* of the problem. In each case, we challenged students to provide not only a *claim*, but also *data* (peer-reviewed sources and credible news accounts giving evidence that the claim is true), followed by a *warrant* or explanation that logically connected the data to the claim.

When students arrived at the design phase (in the second half of the term), they combined their burgeoning knowledge of sanitation engineering techniques and technologies with their understanding of cultural practices – simultaneously elevating technical competency with a humanitarian disposition. Students were required to create a design that addressed local contexts while paying careful attention to existing technologies and practices. They had to understand the characteristics of local communities and their designs had to accommodate needs, culture and constraints. Faculty tracked student progress through regular poster critique sessions and team meetings with engineering and humanities instructors.

Module: Stakeholder Analysis
As the UN notes, "Effective water and sanitation management also depends on the participation of stakeholders" (United Nations, 2016b). Therefore, we had students develop stakeholder analyses early in the term, while scoping the problem, which they continuously updated throughout the term. Students were trained to systematically gather and analyze qualitative information to determine whose interests should be taken into account for their project. They identified and sorted interested parties, highlighting actors of greater and lesser influence (power) and greater and lesser interest.

Module: Gender Analysis
Similarly, we required students to create multiple iterations of a Gender Analysis, reinforcing the idea that gender differences and gender-based inequalities shape the way decisions are made, how resources are allocated and how people interact with the world (Momsen, 2004; Parpart et al., 2000). We note that a gender analysis is a consideration of how women and men, and boys and girls experience a situation differently. A gender analysis is not solely an examination of how women's lives are affected, although on issues related to safe sanitation, women bear a disproportionately high burden of disease and lack of access.

We organized the gender module around the ADAPT framework for gender programming (OCHA, 2012). In this method, students Analyze gender differences; Design services to meet the needs of all; show that their solutions provide equal Access for women, men, girls and boys; explain how community members are enabled to Participate equally; and show how their designs Train men and women equally. Students incorporated gender-specific concerns and constraints in papers and projects and posters and they identified how gender awareness informed their solutions.

> *"When it came down to making a decision on a method we were guided greatly by the idea that we wanted a solution that could not only better the lives of an entire community, but could also better the lives of women so that they have greater opportunity and access to necessary resources."*
>
> Excerpt from final team report

"Women have more sanitation needs than men due to menstruation, and are more inhibited by social stigma and concerns for safety when open defecation is the only option….While all citizens of the village suffer, they do not suffer equally."
Excerpt from final team report

"While working to solve the sanitation crisis in Port Moresby, Papua New Guinea we had many ethical considerations that guided our choices…. We first had to analyze the culture and the interactions between men and women to fully understand the dynamics of the community."
Excerpt from final team report

Data Analysis Procedures & Assessment
We employed a mixed-methods, triangulated approach to assessing the course and student learning outcomes. Indirect instruments included standardized university course evaluations, a customized Student Assessment of Learning Gains survey (SALG), an end-of-course focus group, and a pre/post open prompt survey. For the first offering of the course (spring, 2016) we used the SALG survey and the focus group as primary indirect assessments. Direct methods included student course work samples (a variety of written work, posters, presentations and final projects), a pre/post analysis of a scenario involving hazardous chemicals, and a video-recorded session of teams analyzing an ambiguous scenario indirectly related to course content. We used several of these instruments more than once in the two course offerings and we have an extensive collection of student artifacts. Only a sample of the total assessment plan is reported here, and we emphasize that these are preliminary results at the time of this writing.

Our goals were twofold: to understand the development of student *knowledge* about the engineering and humanistic facets of sanitation, and to understand student engagement with these issues. We wanted to know how much students knew, and cared, about sanitation by the end of the two-course sequence. A summary of the three assessments reported here is shown in Table 2.

Table 2: Summary of Relevant Assessment Methods

Instrument	Description	Application
Student Assessment of Learning Gains (SALG)	Nationally validated survey asking students to connect their own learning with specific course activities	End of Spring 2016 semester
Focus Group	Open-ended discussion on student experience moderated by external consultant	End of Spring 2016 semester
Video Assessment	Team-based analysis of an open-ended, ambiguous scenario	End of Fall 2016 semester

Assessment 1: SALG

This survey asked students to rate their own learning gains with regard to several topics. We used a Likert scale where 1 = no gain, 3 = moderate gain, and 5 = great gain. Regarding their knowledge of waste treatment technology, the importance of society and culture in engineering, and the relationship between humanities and engineering, in each case no student reported a gain lower than moderate. 75% rated their gains at 4 or 5, for averages of 4.2 in each of those three prompts.

Additionally the open-ended prompts at the end of the survey suggest that students had an improved appreciation for the topic of sanitation and its importance in society. Some relevant quotes are:

> *"I have a better understanding of the variables one must take into consideration when addressing sanitation issues, such as culture, available resources, and community involvement."*
>
> *"I had never considered working on solving sanitation issues in my engineering career. This course has made me realize the great potential we have as engineers to address (these) issues."*
>
> *"Before this class I was unaware of all the problems that are going on with waste management"*
>
> *"I am vastly knowledgeable in topics regarding sanitation and hygiene due to this course. It presents a new way of thinking when approaching problems, that I enjoyed. "*
>
> *"I previously did not ever really think about this topic. It was just never made aware to me. It is surprisingly interesting. The field seems as if there is plenty of room to grow in it."*

Assessment 2: Focus Group

An external consultant conducted an end-of-course focus group that 90% of the enrolled students attended. Some students described increases in both enjoyment of class content as well as their understanding of the scope of engineering problems.

> *"I learned some head knowledge [sic] like things about Worcester that were particular about our project, but what I like about this class is that, at least for freshmen, it exposes you to how to think about engineering as how it pertains to humanity and as far as how you can apply it to real world problems, and helping people in an ethical kind of way."*
>
> *"I would say this course resembles some type of eye opener. It really forces you to think about normal engineering problems that you would've thought of a certain way at the start of the term completely differently by the end. I have a totally different mindset on the way I go about doing things now just because I know*

about the effects it has on all these other different type of organizations and people."

Students reported that a tour of the Blackstone Valley Waste Treatment facility helped them experience large-scale waste treatment and make connections among engineering topic lectures and applications. The excerpt below is typical of the student reactions to this trip, highlighting the importance of experiential learning.

Student*:*	*I think that was one of the most fun field trips of my life…we learned about different parts of the plant before we went….Then we got to go there and see them in real life. It was kind of like taking the engineering that we learned here and then seeing how it applies in real life, which I thought was really interesting.*
Facilitator:	*Did that have any kind of impact on you aside from saying oh, this was interesting? What did that do for you?*
Student*:*	*I think it related to a lot of our projects, at least ours in a way, some of the chemistry behind it, like the part where they settle out…and they chemically treated everything. Our project is about treating some water chemically to make it drinkable. It applied to our project to see how our smaller project to be—how it could turn into the future.*

Following the second course offering (Fall, 2016), we employed two new direct assessments. These were a pre/post scenario analysis and a team-based problem solving session that was video recorded. The video sessions aimed to probe students' ability to use course concepts in a context somewhat removed from those addressed during the course, and to assess their teamwork skills. We report only on the video analysis here.

Assessment 3: Video Assessment

Fifteen of the 17 enrolled students in the fall offering volunteered for a recorded session where they were put into random teams and asked to discuss a scenario and prepare a written response. Each team was audio and video recorded and the sessions transcribed. Through coincidence or other unknown reasons the five teams ended up same-gendered. Although this will be avoided in the future, some interesting results emerged, perhaps because of that demographic. We identify the teams as follows: F1 and F2 (all-female teams), M1, M2, and M3 (all male teams).

All student teams were given the same photo and brief scenario. The photo was one of Dorothea Lange's less widely recognized images of Dust Bowl migrant families. The instructions asked students to view the photo through the lens of someone at an assistance agency, and to determine what they could about the conditions of this family in order to recommend interventions that would improve their lives. The image contained two very young children and one slightly older female. We purposefully gave few details and left the kind and extent of intervention completely open-ended; this was to encourage students to think as broadly as they could.

Concern about Sanitation

Three of the five teams addressed sanitation issues in their discussions. Surprisingly, two teams did not mention anything related to sanitation and one team had only a passing reference. This was despite all teams having just completed significant self-generated projects dealing with sanitation in the developing world and an experiential classroom activity designed to help them think about the many dangers associated with open defecation. Our video evidence shows that each team took this end-of-course assessment seriously and did discuss many issues that were pertinent to the photo they analyzed and that were relevant to humanitarian engineering principles. Perhaps the somewhat different nature of this exercise prompted them, appropriately, to think outside the course context. Maybe the prompt was simply too far removed from course topics? Further offerings of the course will likely provide more data and insight.

Below are some discussion extracts typical of the sanitation issue.

F2

Speaker 3:	How do they defecate? People, what have we have been working on?
Speaker 2:	This is what we've been doing.
Speaker 3:	What is the toilet? Yeah. Where, how do they do it?
Speaker 3:	Where do they defecate? What happens with the human waste?

M2

Speaker 1:	Oh, we forget to ask how do they take a dump. That's important.
Speaker 2:	That's a good one.
Speaker 4:	Where does their waste go?
Speaker 2:	If there is no—
Speaker 1:	Toilet.
Speaker 2:	- no sanitation facilities.
Speaker 2:	…Provide somewhat maybe a form of a squat toilet.
Speaker 2:	You just made designs, so we could use it. For safe defecation/urination.
Speaker 4:	All right, so at the moment, we have secure a food water source, improve shelter, find parent/guardian, diagnose, treat any health ailments as well as mental ... find a new home that provides them basic necessities. Educate them. Sanitation facilities. Oh, how do we lighten their moods?

Well-Being

Both female teams had discussions regarding the specific safety of the people in the photograph, while the male teams did not. However, all teams had exchanges about the perceived or apparent look of unhappiness on the children's faces and what could be done to improve their emotional health once basic needs like food and water were met. They also mentioned the lack of a caring parent or guardian implying concern for their protection and well-being. Some relevant quotes from three of these exchanges are shown below.

F2

Speaker 3:	Yeah. We want them together.
Speaker 3:	It's complicated.
Speaker 4:	So sorry for them. They're just trapped…

F1

Interviewee 2:	What type of intervention or interventions would we recommend? I feel the water. The water is a big thing because water is a basic—
Interviewee 1:	At least giving them a water source until wherever they move—assume that that place has water.
Interviewee 2:	Because that's one thing you can't live without.
Interviewee 1:	Water source… Also, because there are kids and, because there's obviously no one looking after them, I guess another intervention could be placing them in a settlement where there are other adult figures that will look after them? Just makin' sure that there is someone being held accountable for them. Also, because they are homeless, making sure that the intervention does include some form of shelter for them.

M2

Speaker 2:	All right, so at the moment, we have secure a food water source, improve shelter, find parent/guardian, diagnose, treat any health ailments as well as mental…find a new home that provides them basic necessities. Educate them. Sanitation facilities. Oh, how do we lighten their moods?

Results and Discussion

Below, we report on student learning gains in humanitarian engineering – both the technical competency necessary to work effectively toward the UN Sustainable Development Goals, and the disposition to care enough about these goals and the larger principle of social justice to want to help meet them. Appreciating complexity and developing cultural competency is no small task, and is not one we presume to have fully instilled with this class. There is some indication, though, that we trained students to think across disciplines and appreciate the complexity of sanitary engineering problems, which was not always an easy or comfortable endeavor.

> *"To some, ambiguity is freedom. To others, it is a shapeless vehicle of anxiety. We find ourselves constantly in both positions. While it is wonderful when ambiguity means freedom, we've learned that it means that we've got to bite the bullet other times and create our own guidelines. This means making some decisions without knowing everything, and parts of us scream disaster whenever we do. The other parts know that limitation means more specificity, and more specificity means a starting point from which we can progress."*

Excerpt from a final team report

"The issue at hand is very complex, full of overlapping problems and layers of factors to keep in mind."

Excerpt from a final team report

We designed assignments and activities to challenge students on their assumptions about the developing world and to encourage them to discard erroneous assumptions. We continuously highlighted the importance of combining human context and engineering in order to avoid obvious failures. We also motivated them to stay flexible and to expect that their ideas and designs will adapt as their understanding deepens. Furthermore, for many students, this course was an early immersion into team-building and team management, skills that are particularly important at a project-based learning institution, and which will be vital in their professional lives. The fall offering (from which we extracted much of the evidence presented here) was limited to newly matriculated students. Hence, they were not only faced with a unique course but they all were experiencing the usual academic and other adjustments to entering college. We would expect that to be particularly stressful for the several international students in the class.

Our early conclusions are that student learning outcomes in the areas of ethics, social justice, and empathy – the "human" in humanitarian engineering – appear at levels consistent with our expectations, although integration of human issues was occasionally uneven. For example, many student reflective essays were exceptionally thoughtful. However, near the end of the course, as teams were bringing their project work to completion, they began to overlook gender and stakeholder concerns in their race to produce models and posters. Several teams failed to transfer their learning from earlier class sessions and written work to the more open-ended project work at the end of the course. We also observed this phenomenon with the technical learning outcomes.

Results regarding engineering learning outcomes were mixed and somewhat problematic. We had an ambitious goal of introducing a variety of basic topics in an integrated structure and seeing those concepts applied as students developed their projects. This is different from the traditional format, where, for example in a fluids course, basic flow principles would be followed by increasingly complex fluid concepts throughout the course. Instead we introduced basic concepts from several, typically separated, courses (conservation of mass/energy, fluids, process design, etc.) that we anticipated students would use as needed in their project work. One co-author has had successful experience with this integrated approach in a project-based context, so we knew it could work. However, our experience was that learning gains were inconsistent. For example, students could do appropriate fluid flow calculations on well-defined homework and lab work. Yet, when faced with making very similar calculations about gravity flow of sewage in their project focused in Rocinha, Rio de Janeiro, they floundered with the lack of given information in this new context and they needed considerable coaching.

There are several possible reasons for this kind of segmented learning and lack of transference. These include student confusion associated with multiple instructors and teaching styles, insufficient amounts of practice in basic calculations, and lack of experience in dealing with ambiguous technical problems. We are working on addressing those as we design the next course offering. One important change is that we are moving the course to the spring semester. This will mean the issues of college adjustment will be largely minimized and students will have completed six courses worth of academic experience as they enter our course – as opposed to none.

We will also address some of the transitional problems we observed in students moving from the first course with its historical focus to the second course with its modern-day focus. We expected that the poster presentation skills they developed during the role-play would improve by the end of the course, but posters produced in the first course were better than those produced seven weeks later. Perhaps we expected too much and tried to address too much material and too many diverse concepts in too short a time period. We are not yet convinced that is the case. We do plan to resume the role-playing in the second half as students start working on their major projects, so they are reminded of what it means to really think from a different point of view.

To help readers realize how our students responded to those different points of view, we offer these excerpts from student project reports, written in response to our request for reflections on the process itself:

> *Throughout our project, we had to consider more than just the math and science involved in the solution. As humanitarian engineers, we are being trained to also focus on the human side. A solution is not complete without an understanding of the environment consideration on the people it serves.*
>
> *Throughout this project, we grew as students and as engineers. Prior to this project and this class, we were not as knowledgeable on the complexities that go into a solution. A large amount of solving the problem was just working towards a better understanding of the problem. This was not something that was obvious before we began this project.*
>
> *A large part of this project was realizing how complex the world is. We learned to deal with the gray areas and feel comfortable with things that were not black and white.*
>
> *The class reminded of the reality that there are real people in need of this solution and even though the problem may only exist thousands of miles away, the people involved must be considered nothing less than a neighbor or a friend.*
>
> *Humanitarian engineering is concept of incorporating a humanitarian mindset into every aspect of an engineered solution. It is the responsibility of the engineer to remember the marginalized and prevent further marginalization in the implementation of the solution.*

> *In any situation where one is affecting others' environment or way of life, one must make sure their actions are culturally appropriate, maintain or elevate the dignity of, and are respectful to those affected, as well as holding one's actions to a high ethical standard.*

Conclusion and Future Directions

Despite the shortcomings discussed above, we believe students showed the will and competence to work toward the Sustainable Development Goals and to consider issues of social justice. They demonstrated acceptable levels of engineering knowledge but within some contextual constraints. It is our wish that students will apply the knowledge they gained in Humanitarian Engineering: Past and Present to other academic projects and in their careers. We hope they see the connections between past and present; between here and "there" and between ourselves and others —and that they will come away with a greater appreciation of our similarities rather than our differences. We do plan to review our complete assessment portfolio and improve it as needed. And, we will develop additional assessments to evaluate any longitudinal retention of humanitarian engineering learning outcomes as students proceed through their academic careers.

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