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Bringing Sustainable Development Challenges into the Engineering Classroom: Applying Human Centered Design Protocols to Artisanal and Small-Scale Mining

Dr. Nicole M. Smith, Colorado School of Mines

Dr. Smith is an Assistant Professor in the Mining Engineering Department at the Colorado School of Mines. She is a cultural anthropologist with research and teaching interests in livelihoods and extractive industries, artisanal and small-scale mining, engineering education, and sustainable development and mineral resources.

Benjamin A Teschner, Colorado School of Mines
Prof. Robin Bullock, Colorado School of Mines

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Abstract
In the United States, the growth of programs in the past decade such as Humanitarian Engineering and Engineers Without Borders reflects student interest in understanding the challenges facing communities in the developing world and applying engineering design principles to address these challenges. These programs also provide students with unique opportunities to engage with stakeholders, a critical element of any sustainable development initiative. Although there is no substitute for taking students to the field, there are not always the resources to do so, and thus, engineering educators must find creative ways to expose students to the ways in which they can support sustainable development goals and engage with stakeholders. This paper reports on two activities focused on incorporating sustainable development projects into engineering design courses. Both approaches were part of larger projects aimed at reducing or eliminating the use of mercury in mineral processing systems used by artisanal and small-scale mining (ASM) communities in Latin America. In the courses discussed in this paper, interdisciplinary groups of undergraduate engineering students were assigned design challenges that focused on developing context specific, mercury-free, mineral processing technologies for ASM communities. The students were required to employ a Human-Centered Design (HCD) protocol, with a significant stakeholder engagement component. Through an analysis of student feedback, this paper identifies two major themes. First, integrating sustainable development projects into the engineering design classroom provides students with deeper insights regarding the challenges of sustainable development projects. Second, students are able to make a clearer connection between the social and technical aspects of engineering and sustainable development problems. This paper concludes that introducing sustainable development projects into the engineering classroom that have real-world applications and allow students to engage in stakeholder engagement activities provides students with knowledge and skills that will benefit them in their future careers as engineering professionals.

Introduction

In the United States, the growth of programs in the past two decades such as Humanitarian Engineering (HE) and Engineers Without Borders (EWB) reflects student interest in understanding the challenges facing communities in the developing world and applying engineering principles to address these challenges. There have also been efforts in academia and industry, in collaboration with organizations like EWB, to define a *global engineer*, who acknowledges that his or her expertise is critical to sustainable development efforts and who "takes into account socioeconomic realities and [is] sensitive to cultural differences" (Chan and Fishbein 2009: 6). Furthermore, it has been suggested that engineering students who plan to engage in sustainable development initiatives develop a set of global competencies (Lucena et al. 2008) and move from being mere "technology advocates" to "Honest Brokers," who research and present a range of technical possibilities within the "broad contextual constraints of the problem-setting" (Mitchell et al. 2004: 40).

Engineering programs globally have responded to these calls for a shifting paradigm in engineering education by introducing innovative curricula that combines social and environmental concerns with economic and technological development (Ahrens and Zascerinska 2012; Lucena and Schneider 2008; Taoussanidis 2010). While there are still questions about the best methods for incorporating sustainable development concepts and applications into engineering curriculum and the impacts this has on student learning, even less understood are the ways in which student learning is impacted through curriculum which actually allows them to engage with stakeholders who are targets of or collaborators in sustainable development initiatives.

This paper begins to fill this gap by examining the results of introducing two different sustainable development projects into two existing courses at the Colorado School of Mines (Mines). In both of the courses, students were required to design and build technological interventions for artisanal and small-scale mineral processing systems in Latin American countries, as part of larger projects aimed at reducing or eliminating the use of mercury in these systems. The courses employed Human-Centered Design (HCD) protocols, which involved students in stakeholder engagement activities and required them to incorporate stakeholder feedback into their design decisions. Through final student reflections on the courses, two major themes emerged. First, students qualitatively demonstrated that these activities provided them with more acute understandings of the challenges of engaging in sustainable development projects, in particular the time and communication constraints. The second theme that emerged is that students were able to make clear connections between the social and technical aspects of engineering and sustainable development problems and reflect on their roles in sustainable development initiatives. This paper suggests that exposing engineering students to sustainable development concepts and activities through classroom projects where they apply HCD protocols and engage with stakeholders enables them to increase their knowledge and skills and will support them in becoming more effective and successful engineering professionals.

Sustainable development and engineering education: Community engagement through human centered design

Engineers are pivotal actors in sustainable development, as they are often viewed as problem solvers and as sustainable development plays a more central role in industry business strategies (Taoussanidis and Antoniadou 2006). While the engineering profession is founded on its commitment to improving societal welfare (Wisnioski 2012), in the last twenty years engineering organizations have institutionalized this commitment through declarations and codes of ethics. For example, in 1999, the American Society of Engineering Educators released a 'Statement on Sustainable Development Education and more recently, the American Society of Civil Engineers released a policy statement in support of the United Nations Sustainable Development Goals (ASCE 2016). At the international level, initiatives such as the Declaration of Barcelona, which resulted from the 2004 Engineering Education in Sustainable Development conference states, "the world and its cultures need a different kind of engineer, one who has a long-term, systemic approach to decision making, one who is guided by ethics, justice, equality and solidarity, and has a holistic understanding that goes beyond his or her own field of specialisation" (Declaration of Barcelona 2005).

The increased interest in and attention to engineers' roles in sustainable development have coincided with complementary initiatives in engineering degree programs, and sustainable development has made its way into engineering education curriculum in a variety of forms (Lucena and Schneider 2008). There is still a question of the most effective method through which to introduce engineering students to sustainable development problems and approaches. Arguably, a method that complements the culture of a particular university and program, will be the strongest determinant of success. However, an audit of higher education engineering curricula conducted by the Sustainable Development Education convened by the UK Department of the Environment, Transport, and Regions in 1998, concluded that sustainable development education "is best integrated into the context of the specialism, and that different learning activities and learning materials will be needed to deliver the sustainability learning agenda to students from the different branches of engineering" (cited in Perdan et al. 2000: 269).

Complementing this perspective, in the late 1990s, the Chemical Engineering Department at the University of Surrey in the UK embarked on an ambitious "Teaching Sustainable Development to Engineering Students" initiative, where they attempted to expose engineering students' to sustainable development concepts throughout their undergraduate careers. Faculty members involved in this initiative created modules, case studies, and creative IT platforms that could be inserted into their engineering courses. These programs culminated with a student design project where students built a plant or facility taking into account sustainable development principles (Perdan et al. 2000).

Other engineering programs have advocated for the incorporation of active learning methods to engineering curriculum, including project based learning and a combination of *forecasting*, which makes predictions on how a scenario will development based on current and historical patterns, and *backcasting*, which begins by defining a set of desirable futures and then identifies feasible paths from those scenarios to the present. These processes allow students to contextualize their work and create visions based on sustainable community development principles (Mitchell et al. 2004). Some programs have developed stand alone courses, such as Sustainable Community Development for Engineers at the Colorado School of Mines while others, such as the Center for Sustainable Engineering, a collaboration among Carnegie Mellon University, Arizona State University, and the University of Texas at Austin, have focused on developing sustainable engineering modules that can be inserted into existing courses (Allenby et al. 2009). While all of these teaching methodologies allow students to gain strong theoretical foundations in sustainable development concepts and principles, they lack a significant stakeholder engagement component.

Community based efforts and stakeholder engagement are key in sustainable development initiatives. Since the late 1980s, engineering schools around the world have created EWB chapters. As voluntary membership organizations, EWB programs engage students in service-learning projects where they form partnerships and work with communities in addressing their development goals. Programs of this nature are invaluable for providing students with direct, hands-on experiences, a greater awareness of the complexity of engineering problems and development challenges, and the ability to interact with people from different cultures and countries (Amadei and Sandekian 2010). Although there is no substitute for immersing students in fieldwork where they are able to engage with stakeholders, students do not always have the resources to participate in such programs, and faculty members often lack funding to support undergraduates to travel internationally and engage in sustainable development efforts. Thus, engineering educators must find creative ways to expose students to sustainable development projects and provide them with the opportunity to interact with stakeholders. Classroom projects, which incorporate HCD protocols, are effective for accomplishing this task.

Human centered design, and its close cousin, user centered design (UCD) are central to sustainable development initiatives as they consider stakeholder-supplied feedback central to the design challenge. These methods employ an iterative approach and focus on incorporating data about stakeholder needs and socio-economic constraints *before* conceptualizing the technical considerations that normally dominate engineering design thinking (Thomsen 2013). The HCD approach begins by asking "Who are the stakeholders of this project?" and "What do these stakeholders want/need?" (International Development Enterprises 2011:7*)*. Design solutions are then created to be desirable to stakeholders, technically feasible, and financially viable (Figure 1). HDC approaches have produced context specific, sustainable technological interventions around the world, including in-home toilets for poor urban households in Ghana and mechanized seeding machines for rural farmers in Ethiopia (International Development Enterprises 2011, 2015).

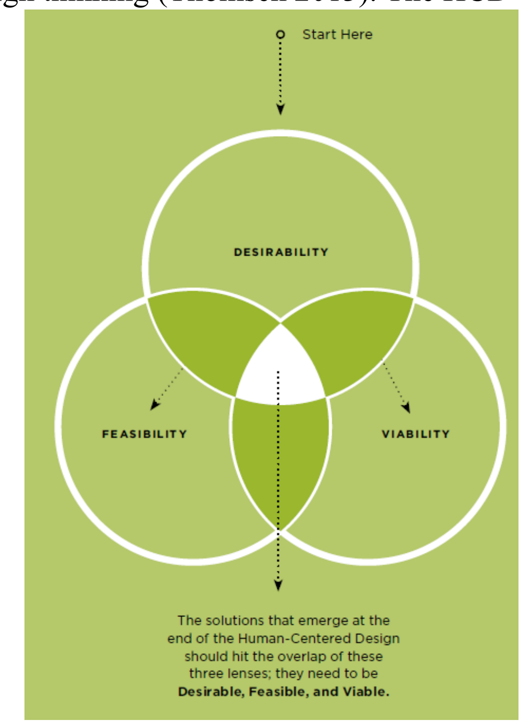

Figure 1: HCD designs must be desirable to stakeholders, technically feasible, and financially viable (International Development Enterprises 2011, 7)

Engineering education has increasingly taught HCD approaches and the skills needed for design thinking (Zoltowski et al. 2012: 29). There are a number of studies that examine the process of HCD approaches (Scott 2008) and students' experiences with and understandings of HCD (Zoltowski et al. 2012). However, applications of HCD approaches to sustainable development are lacking, and HCD has a significant role to play in contributing to sustainable development and teaching engineering students about the ways to understand and approach these development challenges.

ASM and mercury use as a sustainable development challenge

The artisanal and small-scale mining (ASM) sector produces up to 20% of global minerals and metals (Veiga and Baker 2004), and some estimates place the number of people working in ASM at over 50 million. In addition, for each person employed directly in the ASM sector several more are dependent on the activity as part of their livelihoods (Hilson and McQuilken 2014). The number of people who depend on ASM is steadily increasing, and ASM continues to be an important livelihood strategy for rural people worldwide. However, ASM is a livelihood that poses significant risks to human health and the environment and a challenge for policy and regulatory initiatives (Smith et al. 2016).

Because of the risks and the challenges associated with ASM, countless initiatives to formalize the sector, introduce new technologies for cleaner and safer practices, and other development interventions have been put in place among ASM communities across the globe. One of the most exposed harms of ASM activities, and perhaps the focus of the majority of the interventions, is mercury use in mineral processing systems. Artisanal and small-scale miners add mercury to ore to aid in the gold recovery process. Some of this mercury binds with gold particles to form a gold-mercury amalgam, which is then heated. Through this process, the mercury is volatilized into the air, leaving the gold behind and significant amounts of mercury are lost to soils and waterways. ASM is a major source of global mercury pollution, and the largest anthropogenic source of mercury emissions globally (United Nations Environment Program 2013). Unlike other industrial uses of mercury, nearly all of what is used by ASM ends up in the environment; approximately 40 percent is released into the air, while most of the remaining 60 percent is lost into waterways and soil (Telmer and Viega 2009).

Aid organizations, scholars, and a handful of small companies have developed alternative gold processing technologies which attempt to improve recovery rates while reducing or eliminating the need for mercury. Although some of these devices have been shown to improve gold recoveries and reduce mercury use (Viega and Baker, 2004), these technologies have had limited success in widespread implementation or long-term sustainability. Authors have documented that technology adoption failures come from a complex set of variables including a lack of knowledge about the technology and its effectiveness, the inability to afford upfront costs or ongoing repairs of a given technology, or the notion that the technology is inappropriate for local conditions (Duflo et al. 2004; Hilson and Vieira, 2007). These findings align with Hilson et al's (2007) critique of mercury-reduction projects applied to ASM: "there has been a fixation on implementing generic technologies…as opposed to site-specific solutions." Furthermore, Hilson and Vieira (2007) observe that few interventions have been effective because of a lack of input from miners before the design and implementation of new technologies. Reducing or eliminating mercury use among the ASM sector must be informed by a collaborative approach involving multiple stakeholders, particularly members of the targeted community and be based on an interdisciplinary perspective that is attentive to the specific social, political, economic, and environmental contexts in which these initiatives take place.

Introducing students to ASM

The goal of this exercise was to introduce projects into two design courses at Mines and assess the ways in which HCD protocols, which included significant stakeholder engagement components, impacted students' understandings of sustainable development and their perceptions of their roles in sustainable development initiatives. One of the selected courses was, *Projects for People*, and the other was the College of Engineering and Computer Science (CECS) *Senior Design Capstone* course. The courses were chosen because of their focus on applying HCD protocols, as well as the instructors' willingness to participate in the project. Also, both of the courses are required for students enrolled in the Humanitarian Engineering (HE) minor. The HE program, home to the HE minor, began at Mines in 2006 with the goal of providing educational opportunities for students to learn the ways in which engineering can create just and sustainable solutions *with* communities. Because of the significant social and technical dimensions of artisanal and small-scale mining, the course instructors decided that this topic was appropriate for HCD protocols and would enable student to engage in real-world design challenges *with* communities and other stakeholders.

The projects introduced into each course were part of larger research investigations led by an assistant professor in the Mining Engineering Department at Mines, who has a PhD in anthropology (hereafter referred to as the "PI") and who has conducted research among ASM communities for the past few years. The students in the Projects for People course worked on an intervention to reduce mercury use in ASM processing systems in Peru, as part of a US Department of State funded project. The students in the Senior Design course worked under an EPA People, Prosperity and the Plant (P3) grant that funded them to design an intervention to reduce mercury use in ASM processing systems in Suriname. Both projects aimed to provide students with the opportunity to interact with key stakeholders and co-design their interventions; however, the particular stakeholders the students interacted with and the forms of interactions they had with these stakeholders were different in each course.

Projects for People
Projects for People is a semester long course that is required for students who are enrolled in the HE minor. It is also open to any other student at Mines and counts as an upper-level elective. In this course, students work on community development projects and design engineering solutions to real problems affecting real people. The course focuses on HCD protocols, project scoping, research techniques, brainstorming tools and approaches, technical writing and presenting, and technical topics as needed for the design challenge. It is a combination of lecture hours and a lab. At the conclusion of the course, it is expected that students will achieve the following learning outcomes:

1. Apply appropriate technical knowledge to solve a design challenge as demonstrated by peer review and partner review.
2. Demonstrate empathy for the end user/community for which they are designing.
3. Describe the environmental impacts of the technical solution, which they are designing.
4. Build low cost, physical prototypes of ideas and concepts.
5. Develop a technical engineering documentation package.
6. Work in teams over the course of several design sprints.
7. Complete a lessons learned assignment, which allows reflection on the social, environmental and technical outcome of the semester.
8. Present work graphically and verbally for critique.
9. Write a final report summarizing the progress made over the course of the semester.

The instructor who taught the course in Spring 2017 has a BS and MS in Environmental Engineering, and she will complete her PhD in Civil/Environmental Engineering this year. She has extensive industry experience in engineering, remediation and decommissioning, risk and crisis management, and corporate social responsibility and she has been teaching engineering design principles at Mines for 2½ years. There were sixteen students enrolled in the course during Spring 2017, representing mechanical engineering (n=12), chemical engineering (n=1), geophysics (n=2) and civil and environmental engineering (n=1). All of the students were seniors, with the exception of one mechanical engineering student who was a junior.

Projects for People ASM Challenge

The PI of the State Department grant and the instructor of the class designed a semester-long project that tasked the students with creating modules that would provide education and training for artisanal and small-scale miners and their communities. The modules were chosen based on mineral processing and health and safety analyses led by a Latin American-based non-governmental organization (NGO) partnering on the project and a project kick-off workshop in Lima, Peru attended by faculty members and students from Mines and partnering Peruvian universities, NGO staff members, and ASM community members. These activities allowed for important exchanges where ASM community members aided the partnering organizations in understanding their work and the context in which it takes place and help identified major issues that the project had the capacity to address.

As part of the HCD protocol, the students received the stakeholder and technical data from these exercises and also benefited from the knowledge and experiences of two students in the class who were research assistants on the project prior to the start of the course and who traveled with the PI to Lima a month before the course began to participate in the stakeholder workshop. The students in the class divided into five groups according to the module in which they had the most interest. Each group worked on one design challenge. A few weeks into the semester, the groups began to collaborate with five engineering students and a faculty member at the Universidad de Ingineria y Tecnologia (UTEC) in Lima. The UTEC students volunteered to participate in the project and were juniors and seniors in industrial, mechanical, and environmental engineering degree programs. The delay in the collaboration was because the different academic calendars of the two universities. For practical purposes the Mines students started on the project, and once the semester at UTEC began, the students were able to collaborate moving forward. Once the semester ended at Mines in May, the UTEC team took over the designs.

The stakeholder engagement component of the project included two primary activities. First, the Mines students and the UTEC students collaborated for eleven weeks on the designs and specifications of the training modules. Because the groups at Mines were required to meet certain stage-gates as part of the course, they were able to dedicate more time to this stage of the project; however, the UTEC students provided valuable feedback on the designs and detailed information on the cost and availability of materials that could be used to build the designs locally. The groups connected each week through Skype conversations or email and created shared file management systems through Google Drive.

The second stakeholder engagement activity occurred in June after the semester ended for the Mines students. In June, the project PI traveled to Peru and accompanied the partnering NGO, and four of the UTEC students to the community where the training modules were to be implemented. After several days of interviewing miners and mineral processors and a project meeting with community members, the team discovered that some of the modules were irrelevant or that changes needed to be made to the design. The UTEC students were able to use this information to make further revisions with input from the NGO.

Senior Design Capstone

The Senior Design capstone course is required for Mechanical, Electrical, and Civil and Environmental Engineering students during their senior year at Mines. The course spans two semesters (generally fall and spring) and is intended to give students practice in the engineering design process. In the course, under the direction of a faculty advisor and a project "client," interdisciplinary teams of 5-7 students demonstrate design integrity and performance by building a prototype or model, producing a complete drawing and specification package, and performing experimental tests to verify their design. They students are to apply HCD protocols by interfacing with users, developing multiple conceptual solutions to present for stakeholder and faculty feedback, and create a proof-of-concept prototype of a final design solution. The course culminates in a trade fair, where students present their projects to clients, faculty members, and industry partners and compete for recognition.

Out of approximately forty capstone projects each year, only a few qualify for inclusion as HE projects, which means they must have a substantial social element. Students who are interested in the HE projects submit a resume and are interviewed by course faculty, who then build the teams by selecting the students which have the best background, skills, and attitude to excel with the challenge. Being part of an HE capstone project provides the student teams with more direct access to HE faculty and resources and the ability to apply HCD protocols to socially complex challenges. The HE faculty and the PI decided that the ASM project was a strong fit for an HE senior design project. The faculty advisor to the HE team working on the ASM design challenge was a PhD student in the Mining Engineering department at Mines. Prior to the start of his PhD program, he was an instructor in the HE program. He also has an MA in the Political Economy of Resources from Mines and extensive practical experience working with artisanal and small-scale miners as a community development specialist for a mining company.

Normally, the Senior Design capstone course only includes students from the College of Engineering and Computer Science who are pursuing Mechanical, Electrical, and Civil and Environmental Engineering degrees. However, because of the interdisciplinary nature of the project, faculty members in the Departments of Mining Engineering and Metallurgical and Materials Science Engineering agreed to recruit one or two seniors to join the team and receive credit in their home departments. The PI and the faculty advisor sent out recruitment announcements to the incoming seniors during the summer before the project began and interviewed students who were interested in participating. They vetted the selected students through their respective departments and invited one student from Mining Engineering and two students from Metallurgical and Materials Science Engineering to join the team. The other five students were selected through a standardized process where all of the students in the senior design course are presented with the possible projects and apply to their top five. The PI and the faculty advisor for the ASM project chose the team according to the students' interests and the skills needed for the project. This added two Mechanical Engineering students and two Environmental Engineering students to the seven-person team.

Senior Design Course Challenge

The PI of the EPA P3 grant and the instructor of the course, also the Co-PI on the grant, co-designed the framework and objectives for the Senior Design team project. It was designed to span two semesters and was aimed at developing a prototype for an intervention that could reduce or eliminate environmental contamination and human health risks from mercury during the processing of gold ores in ASM operations in Suriname. The team was tasked with the following:

1) Utilize existing institutional knowledge, site-specific data, and interactions with experts and small-scale miners to identify socially and economically appropriate opportunities for mercury reduction or elimination at ASM sites in Suriname
2) Construct a proof of concept prototype of a mercury-free or mercury-reduced process, which demonstrates a viable opportunity for introduction into the Surinamese ASM processing system.
3) Utilize the process of HCD to meet the Humanitarian Engineering Program's pedagogical goals for project-based learning.
4) Develop a methodology for designing and applying ASM technological interventions, which can be used at other sites around the world.

The PI and the faculty advisor conducted fieldwork in Suriname during the summer of 2015. During this time, they collected ethnographic data from artisanal and small miners and community members and data on mineral processing methods and gold recovery rates. They provided the Senior Design team with raw data sets and published articles. They also gave the students ore they collected during the fieldwork in Suriname to use for their experiments.

Perhaps the most significant aspect of community engagement in this course was the collaboration between the student team and an artisanal and small-scale miner and an ASM expert, both from Suriname. Funding provided by the HE Program at Mines supported them to visit the campus for a week in October 2016. During this week, students and faculty members learned more about mineral processing systems and the larger social, economic, political, and environmental context in which mineral processing takes place in Suriname. They were also able to engage with the ASM stakeholders in brainstorming potential prototype designs and assessing the feasibility of these designs. After the ASM stakeholders left, the team spent the rest of the semester working on the design and specifications and then built the prototype during the following semester. In April 2017, they traveled to Washington DC to showcase their prototype in the EPA P3 Student Design Expo.

Student Assessments

Student learning was assessed through standard faculty evaluations administered at the end of the semester with a quantitative matrix of questions and an optional section for a narrative or qualitative response. In addition, at the end of the Projects for People class, the instructor asked the students to write a few sentences on the lessons learned from the class. At the end of the Senior Design course, some of the students participated in discussions with the PI and the faculty lead where they discussed the opportunities and challenges of carrying out the senior design project.

Standard Faculty Evaluations
At Mines, students complete standard faculty evaluations for each class in which they are enrolled. Evaluations are administered through the online course interface, *Canvas*. In Spring 2017, three out of seven students (43%) in the Senior Design course completed evaluations for

spring 2017, and eleven out of the sixteen (69%) students in the Projects for People course completed the evaluation. The Projects for People course response rate reflects the average response rate (70%) at Mines from Fall 2014 – Spring 2016 (https://www.mines.edu/academic-affairs/faculty-resources/student-faculty-evaluations-information/); the Senior Design course rate is much lower, yet the sample size is only six.

The standard faculty evaluation is mainly focused on quantitatively evaluating the instructor's performance throughout the semester. Although the teaching methods and delivery of those methods are closely linked, the instructor's delivery of the material and his/her organization of the course should not be conflated with the extent to which the stakeholder engagement activities impacted the students' learning experiences. The first question on the evaluation, however, may lend insight as to the extent to which the applied pedagogical methodologies generally promoted student learning. The question asks students to respond to the statement: "The teaching methods used in this course are effective for promoting student learning." Students choose from the following options: Strongly Agree; Agree; Neutral; Disagree; Strongly Disagree; or Not Applicable. In the *Projects for People* course, 18% (n=16) of the students strongly agreed, 64% agreed, and 18% marked neutral. The three Senior Design students all marked Strongly Agree in their response to this statement. None of the students in either course disagreed with this statement. While it is not clear which particular teaching methods students were signaling when they responded to this question, taken as a whole, we suggest that the teaching methods, framed around HCD protocols with stakeholder engagement, were effective for promoting student learning. Students' qualitative remarks provide more insights into the ways in which the teaching methods influenced their understanding of sustainable development.

Qualitative evaluations

The students' qualitative reflections on the courses demonstrate that stakeholder engagement was central to their ability to effectively carry out HCD activities.

Projects for People

The Projects for People "lessons learned" exercise allowed students to reflect on their insights from the stakeholder engagement activities. Although some students advocated for a project "we could visit" and more "hands on" experiences, many reflected on the ways in which the project alerted them to the significance of working on real-world problems, including their roles as engineers. One student wrote:

> I have never done a project in a class that would have a real world effect. This gave another dimension to the project that I have never had before. Before when working on a project there could be obvious real life flaws that you could write out on your report. For example, 'If this bridge were to be actually manufactured we would need to do more testing on the soil site...etc' In this project we had to take that extra step and MAKE SURE that what we were proposing would work and know exactly how. Taking that one step further, we were tasked to help change the lives of those who really need it. Not only was this a contractual obligation but a moral one.

This student explains how the potential unintended consequences of the team's design could not simply be reported as a caveat, but needed to be taken seriously and addressed. She points to the fact that there is very little (if any) room for trail and error in sustainable community development initiatives and contrasts this with her previous design experiences at Mines. Remarkably, she describes this as a "moral obligation" above and beyond a contractual obligation, and through this positioning indicates that projects of this nature may reinforce and provide clear examples of engineering ethics. Other students also commented on the "real world" aspects of the project and the implications of this for imposed deadlines. One student wrote:

> . . . just because a basic design was thought of, it took a lot more research and testing to ensure that it would work. This was my first time working on a project where a real life situation supplied the problem, which added many factors that I never thought of on previous projects I have worked on. This was a somewhat rude awakening to me as my group had to change our design multiple times resulting in a rushed feeling the last weeks of class.

While this student expresses that he felt bound by the academic calendar, he demonstrates the disconnect that often exists between engineering deadlines, institutionalized timeframes that drive policy, and agency led timelines for development interventions. He provides an indication of the incongruent timeframes within which different stakeholder groups operate. The fact that his group was willing to change their design "multiple times" reflects the importance they placed on getting it right because of its "real life" implications. Other students provide more self-reflection on the time limitations and recognized that effective communication would have increased their efficiency.

> The communication had to be constant. It was important that it was clear what was expected of who. Our group didn't figure this out until later in the process than we should have and it set us back on time. If more planning was done on the part of my group and we communicated with our contact in Peru more and had a clearer idea of what specifically was asked of us we could have avoided a lot of work that we did that was unnecessary. I feel that this was one of the most valuable lessons learned in this class. The ability to work with another corporation that you have never interacted with or met with in person is a skill I see coming up a lot in my future as an engineer. After this class I have a much better understanding of what working with another company will look like in the future.

This student speaks to the ways in which communication between the two student groups was key in moving the process along. She is able to conceptualize the ways she will apply the skills she learned in the class in her future work as an engineering professional. She underscores the importance of communication to engineering practice. These sentiments were echoed in other students' responses.

> This class has taught me one major lesson about social impact: the difficulties involved when trying to make a "difference" or "change" in another community. I was under the impression humanitarian work would be a lot easier, but I was quickly proven wrong in this class. Humanitarian work requires more effort, more background knowledge, more patience, more questions, and more insights than many engineering problems. Given a regular engineering problem, you don't necessarily need some of the same information

> required for humanitarian problems. . . .Trying to obtain information proved just as hard as solving the problem. Communication between the community and our class was difficult. Also, the lack of cultural knowledge made it difficult to come to a solution that the community would accept.

This student emphasizes the importance of communication, but she frames it within a larger discourse on humanitarian work. She expresses the need for more information—even more than is necessary for a "regular engineering" problem. And she states that it was difficult to access this information. She highlights her unfamiliarity with the nontechnical issues associated with engineering design and alludes to the emphasis in engineering education on close-ended technical problems. But she appears to address this discomfort by recommending more communication and information. Other students echoed this uneasiness although to a much greater extent. One student reported:

> In all honesty, I was interested in humanitarian work prior to this class; however, I have come to learn that I'm not really interested in it or the work involved. This realization isn't a direct result of how the class was run but a result of the amount of work required for a successful project. The project was more work than I expected and has resulted in me learning of my lack of interest in Humanitarian work. The patience, the lack of information, the difficulties getting information and communicating has lead me to realize I'm not cut out for that work. This learning is important for all people to understand. Many people want to make a change in the world, but don't realize how hard it can be. People spend all their time under the impression they can go into humanitarian work, but not everyone is cut out for it.

This student's self reflection is powerful. He acknowledges a departure from his interests in humanitarian work due to the "amount of work required for a successful project." While the goal of introducing community development projects into engineering courses is not to turn students away from potential careers in this area, we contend that these activities can aid students in determining how they want (and do not want) to apply their engineering education. This is a valuable lesson for students to learn early in their careers.

Senior Capstone

The students in the Senior Capstone course were able to effectively articulate that the social dimensions of the project were a significant driver in their design and they emphasized their interactions with the "clients" as critical to understanding these dimensions.

> We learned that it is not always the technical solution that is the right solution. We could have come up with many more plans that would have worked and were cheaper, but by taking into account what the community wanted, we had to prioritize other solutions. The interactions with [the stakeholders] were most valuable. Having them come and physically work with us put us way more ahead of where we thought we would be. It gave us experience working with a completely different country and culture.

This student makes it clear that the team's face-to-face interactions with project clients were critical in shaping their design and valuable for the cross-cultural experience. She also indicates that the engagement strategies employed in this course provided a greater amount of efficiency in meeting the course deadlines. However, as another student elaborates, there were some challenges that emerged in terms of communication between the students and the stakeholders after they left Colorado.

> The first challenge was taking this idea that the [stakeholders] gave us and turning into something physical . . . I liked how the different disciplines in engineering came together and problem solved. But this also created some challenges like agreeing on the prototype design. During the second semester it was very difficult to contact them [the stakeholders], and we received little feedback, which made it very difficult when were building the prototype. We couldn't say to the [stakeholders], 'this isn't working, what if we change this?' There was a lack of communication.

This student emphasizes her appreciation for the interdisciplinary approach, but also describes how this created difficulties for the team. Like the students in the Projects for People course, she brings out the challenges with communication. An additional barrier identified by the Senior Design students, similar to those highlighted by the Projects for People students was the amount of data needed and the time constraints. One student explains, "During the first semester we focused on data collection, and then the second was prototype development. We realized we needed so much data and then there wasn't enough time to build." Furthermore, one student demonstrated keen insight in recognizing that the team was only receiving one perspective. "Having the [stakeholders] here was very helpful. One day our team presented all of the options and the [stakeholders] provided input. They were able to choose the solution. It would have been even better if more miners were there to give their input, because we only got one perspective."

Discussion and Conclusions

There are two major themes that emerge from the qualitative data from both courses. The first theme is related to the practical challenges that the students faced, including time constraints and communications difficulties. The other theme centers around the ways in which these projects allowed students to understand the links between the social and technical dimensions of their design projects. Drawing on these themes, the authors suggest that student participation in sustainable development projects with a focus on stakeholder engagement provides them with an understanding of the complexities of and their roles in sustainable development projects.

The students were very explicit in their descriptions of the challenges they had with the time constraints and the communication with stakeholders. Students commented that the imposed deadlines did not necessarily correspond to the time they need fully understand the suite of issues related to their design challenge. In some cases, this left students feeling rushed, and in other cases, students critiqued their own performance. Development projects often are bound by timelines that are set according to terms that are implemented on the basis of fiscal years or funding cycles. Often, there is little awareness of the time it takes to understand the full suite of factors that impact community practices and decision-making. Whether students work in sustainable development or industry, they will have to find a balance between company driven timelines and the on-the-ground reality of their projects.

Some of the communication challenges cited by both student groups were practical in nature, such as poor Skype connections and a lack of Internet access among the international stakeholders, but the other challenges were because of general communication breakdowns where students felt like they needed more information and were not able to or were not sure how to ask for or access the information. Both of these challenges reflect the fact that the projects implemented into these courses forced students to make decisions with incomplete information but that have high-stakes. The involvement of stakeholders helps to clarify these decisions, yet introduces a different kind of decision-making process into engineering education (Clift 2006), one that is associated with the realm of *post-normal science*, a paradigm that focuses on uncertainty and the value of multiple stakeholders' perspectives and represents a deviation from traditional engineering problems (Funtowicz and Ravetz 1999).

Finally, it appears that these activities spurred a *repolitization* of students' awareness of the connections between engineering and social concerns. In engineering, sustainable development projects have the potential to bridge the socio-technical divide and challenge the "ideology of depoliticization," or, as defined by Erin Cech, a paradigm in the engineering profession that engineering work can and should be disconnected from 'social' and 'political' concerns because such considerations may bias otherwise 'pure' engineering practice" (2013: 48). The students' responses suggest that the emphasis in engineering education on close-ended technical problems blinds them to the interrelatedness of technical and non-technical aspects of engineering (Munakata-Marr et al. 2009). By allowing students to come to this realization through projects that have real-world applications and implications, some students were able to solidify their commitment to HE, while others realized this was not the career path they wanted to pursue.

This paper concludes that bringing projects into the classroom that have real-world applications and allow students to engage in various types of stakeholder engagement activities, provides students with a particular awareness and a set of skills that they will draw from in their engineering careers.

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