Journal of International Engineering Education

Volume 3 | Issue 1 Article 5

2021

Developing Global Sociotechnical Competency Through Humanitarian Engineering: A Comparison of In-Person and Virtual International Project Experiences

Jessica M. Smith
Colorado School of Mines, jmsmith@mines.edu

Juan Lucena
Colorado School of Mines, jlucena@mines.edu

Angelina Rivera
Colorado School of Mines, arivera@mymail.mines.edu

Thomas Phelan
United States Air Force Academy, thomas.phelan@afacademy.af.edu

Kathleen Smits
University of Texas - Arlington, kathleen.smits@uta.edu

See next page for additional authors

Developing Global Sociotechnical Competency Through Humanitarian Engineering: A Comparison of In-Person and Virtual International Project Experiences

Cover Page Footnote

This work was supported by the National Science Foundation under Project Award No. NSF-1743749. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. Further, the views expressed herein are those of the authors and not necessarily those of the U.S. Air Force Academy, the U.S. Air Force, the Department of Defense, or the U.S. Government. The authors would like to acknowledge Professor Oscar Restrepo Baena (Universidad Nacional de Colombia) for his tireless work hosting our team, opening doors for us in the field, managing complex fieldwork relationships, and connecting our students with his own; Libby McDonald (MIT D-Lab) for advising many of our students and carrying forward activities to empower ASGM miners, especially women; Diana Duarte, Alex Freese, and Maria Margarita Gamarra (Diversa/C-Innova) for modeling respectful engagement of ASGM communities, developing and delivering summer session activities, and mentoring our students during the process; and Julia Roos (Mines) for organizing both the in-person and virtual activities, handling the complex logistics of these events, and serving the best interests of our students in the difficult times of the pandemic.

Authors

Jessica M. Smith, Juan Lucena, Angelina Rivera, Thomas Phelan, Kathleen Smits, and Robin Bullock

JIEE
Journal for International Engineering Education

RESEARCH

Developing Global Socioetechnical Competency Through Humanitarian Engineering: A Comparison of In-Person and Virtual International Project Experiences

Jessica M. Smith, Colorado School of Mines
Juan C. Lucena, Colorado School of Mines
Angelina Rivera, Colorado School of Mines
Thomas Phelan, United States Air Force Academy
Kathleen Smits, University of Texas – Arlington
Robin Bullock, Montana Tech

Introduction

One of the key concerns of engineering educators in the wake of the COVID-19 pandemic was its effect on student learning and professional development. These concerns are particularly acute for programs with a significant international dimension, such as our Responsible Mining, Resilient Communities (RMRC) research and education project, funded by the U.S. National Science Foundation's Partnerships in International Research and Education (PIRE) program. RMRC uses multi-country, interinstitutional, and interdisciplinary collaboration to train U.S. engineering students to co-design socially responsible and sustainable artisanal and small-scale gold mining (ASGM) practices with mining communities and engineers in Colombia and Peru. ASGM is mining done by individuals or small enterprises with limited capital investment and production, who oftentimes work informally (i.e., without governmental sanction). The prevalence of ASGM has grown worldwide alongside increasing gold prices and is now estimated to be responsible for approximately 10-15% of total gold production (United Nations Environment Programme, n.d.). While ASGM provides a livelihood for up to 15 million people worldwide, including an estimated five million women and children, it poses significant environmental, human health and safety risks (Cordy et al., 2011; Esdaile & Chalker 2018). It is difficult to provide exact figures of ASGM production and labor statistics, given that the vast majority of this work is done informally. Nonetheless, in 2021 a United Nations consortium estimated that 350,000 Colombians were working in ASGM, producing 87% of the country's gold ("Colombia", n.d.).

One of the engineering education research goals of RMRC is to investigate how *situated learning* enhances undergraduate engineering students' *global sociotechnical competency*, especially as it relates to their ability to define and solve problems with people from diverse disciplinary backgrounds and life experiences, ranging from U.S. social scientists to Colombian miners. Situated learning (Johri & Olds, 2011; Sadler, 2009) refers to how students learn under different circumstances: a) configurations of social relations (e.g., between graduate and undergraduate students; experts and non-experts; U.S. and non-U.S. students, etc.); b) pedagogical strategies for engineering problem definition and solution (e.g., remote vs. in-person; in-class vs. in-field); and c) geographical locations (e.g., U.S. vs. Colombia). In our project, we explore how different kinds of situated learning influence students' development of global sociotechnical competency. Because the COVID-19 pandemic precluded international travel, the transition from an in-person 2019 summer field session to a fully virtual 2020 summer field session provided an opportunity to compare two different formats for student engagement with international engineering faculty, engineering students, and ASGM community stakeholders, which include miners, mine owners, processing plant owners and operators, family members, residents, and government officials.

For the purposes of this article, we sought to answer the following research questions: 1) How did the summer field sessions affect particular elements of students' knowledge, skills, and attitudes related to global sociotechnical competency?, and 2) Were there noticeable differences in student learning or competency between the in-person (2019) and virtual format (2020)? As further background for our study, we begin by offering a novel conceptualization of global sociotechnical competency that synthesizes existing research on global engineering competency (Downey et al., 2006; Jesiek et al, 2014), technical mediation (Downey, 2005), and socially responsible engineering (Smith & Lucena, 2020). Then, we describe how we developed and executed a meaningful remote (virtual) fieldwork experience that maintained direct engagement with international faculty, students, and community members. Next, we share our methodologies for evaluating changes in students' global sociotechnical competency and analyze changes in the pre- and post-session student interviews, essays, and survey responses to assess how each session influenced their global sociotechnical competency. We conclude by discussing findings and implications for educating the next generation of socially responsible engineers.

Conceptual Background: Defining global sociotechnical competency

In their comprehensive literature review of engineering practice in a global context, Jesiek et al. (2014) define global engineering competency as "those capabilities and job requirements that are uniquely or especially relevant for effective engineering practice in global context" (p. 3). Organizing their literature review in categories, they identified three content dimensions of those capabilities and job requirements: a) technical coordination, b) understanding and negotiating engineering cultures, and c) navigating ethics, standards, and regulations. These dimensions are important to understand for engineers practicing in corporate settings. In contrast, our research and teaching does not take place in corporate settings but in the context of hands-on community development projects as a component of undergraduate engineering education. Our notion of global sociotechnical competency extends the work of Jesiek et al. in three additional dimensions.

First, we emphasize the inherent sociotechnical character of engineering practice. The term *sociotechnical* has migrated to engineering education from the field of Science and Technology Studies (STS) but is understood and applied in multiple ways. Frequently, it is not defined by itself but in opposition to that which it critiques: the artificial separation of the technical and social dimensions of engineering, which has been theorized as a technical/social dualism (Faulkner, 2007) that depoliticizes engineering knowledge and practice (Cech, 2013). Educators use the term "sociotechnical" to refer to both engineering itself as well as to the habits of thinking they seek to nurture in students (Adams et al., 2011). One group of engineering educators uses the term sociotechnical to position engineering as "both technical and non-technical (taken to refer to the social, economic, political, ethical, etc.) from the start" (Cohen et al., 2014, p. 5). Another group defines sociotechnical thinking as recognizing the "interplay between relevant social and technical factors in the problem to be solved" (Leydens et al., 2018, p. 1). This approach also animates understandings of a "sociotechnical mindset" that involves the "ability to identify and address issues with an understanding of the complex ways in which the social and technical aspects of these issues are interconnected" by "holding both the technical and the social in one's mind simultaneously" (Hoople & Choi-Fitzpatrick, 2020, p. 6). Still others place more emphasis on students recognizing relevant "social-political factors and multiple stakeholder perspectives that influence engineering" and identifying second-order effects stemming from those "socio-political factors, multiple stakeholder perspectives, and uncertainty associated with the systems and products that engineers build" (Andrade & Tomblin, 2018, p. 3; see also Andrade & Tomblin 2019; Krupczak & Mina, 2016).

As illustrated by the above definitions, a significant challenge is that the very language we use to define what a sociotechnical approach is can inadvertently reinforce the very distinction between the "social" and the "technical" that a sociotechnical approach seeks to dissolve. As STS scholars Bijker & Law (1992, pp. 305-306) explain:

> Technology is never purely technological: it is also social. The social is never purely social: it is technological. This is something easy to say but difficult to work with. So much of our language and so many of our practices reflect a determined, culturally in-grained propensity to treat the two as if they were quite separate from one another.

In other words, distinguishing "technical" and "social" aspects, dimensions, or factors that influence or shape a project can have the unintended effect of viewing the technical and social as separable, rather than inherently co-constituted. As illustrated below, our project aimed for students to not just recognize that there are both technical and social dimensions of an engineering project and that these shape each other, but to see the technical as inherently social and vice versa (Bijker, 1997; Johnson and & Wetmore, 2008; Johnson et al., 2019).

Second, our research and teaching prioritize problem definition, taking inspiration from Downey's (2005, p. 591) notion of engineering as Problem Definition and Solution (PDS):

> In conventional definitions of engineering work, engineers have to make difficult trade-offs among alternative needs or design specifications. In the PDS model, engineers also have to make difficult trade-offs among alternative stakeholders, alternative definitions of the problem, and alternative perspectives about what is taking place, including their own. By defining the human dimension of engineering solutions as, minimally, mediating among the positions of stakeholders, whether between the company and regulatory agency, between workers and management, among workers, among managers, and so on, engineers continue to select solutions to meet technical needs but also to reconcile differences.

This perspective underscores a vital dimension of global competency: acquiring "the knowledge, ability, and predisposition to work effectively with people who define problems differently than they do" (Downey et al., 2006, p. 110). In our case, *knowledge* refers to understanding how engineering problems are always sociotechnical and how both problems and solutions are shaped by the historical, cultural, economic, and physical dimensions of a place. *Skills (abilities)* include learning to define and solve problems with perspectives different than one's own. *Attitudes (predispositions)* refer to the desires to continue engaging other expert and non-expert perspectives, working abroad, and serving communities after graduation. More specifically, we aspired for the summer session to develop students' a) *knowledge* that ASGM is best understood as a sociotechnical supply chain that varies by cultural context; b) *skills* to constructively intervene at different points in the ASGM life cycle in culturally appropriate ways; and c) *attitudes* to work with expert and non-expert perspectives from multiple cultural frameworks in the definition and solution of problems related to ASGM.

Third, we have explicitly based our project on principles of social justice and social responsibility. Whereas the original framework of global engineering competency can be applied to global engineering in any context and for a wide variety of ethical ends that comply with existing codes, standards, and regulations, we add another layer that reflects our goal for students to support people who are marginalized by existing structures of power. To support the goals of community development and social justice, PDS must take place *with,* not *for,* the communities engineering projects seek to serve. We therefore adopt the framework for socially responsible engineering offered by Smith and Lucena (2020, p. 668):

1. Understanding structural conditions and power differentials among specific stakeholders of an engineering project.
2. Contextually listening to all stakeholders, especially marginalized stakeholders, to grasp their needs, desires, and fears surrounding a specific project, decision, etc.
3. Collaboratively identifying opportunities and limitations of creating shared social, environmental and economic value for all stakeholders, especially marginalized stakeholders. This requires acknowledging when stakeholders define "value" differently.
4. Adapting engineering decision-making to promote those shared values, acknowledging situations in which this is not possible and where engineering projects should not move forward.
5. Collaboratively assessing activities and outcomes with stakeholders.

Table 1: Global sociotechnical competency framework

CONTENT DIMENSIONS → **LEARNING OUTCOMES ↓**	**Sociotechnical coordination**	**Understanding and negotiating engineering and relevant national or local cultures**	**Navigating ethics, standards and regulations**	**Socially responsible engineering**
Knowledge	Understanding ASGM as a sociotechnical system	Understanding the history and political economy of ASGM in different countries Understanding the history and political economy of engineering in different countries with ASGM	Understanding legal dimensions of mining, labor & environmental management that animate ASGM	Understanding power differentials; How to have empathy, build trust, and treat expert and non-expert stakeholders involved in ASGM
Skills	Ability to identify different stakeholders in the ASGM life cycle and mediate among their needs and desires Ability to see how "technical" and "social" dimensions of ASGM actually co-constitute each other	Ability to operate differently in ASGM in different countries Ability to work with engineering faculty from different countries with ASGM	Ability to consult experts to ensure that sociotechnical innovations/design projects comply with legal and other regulatory standards relevant to ASGM	Ability to listen, engage in perspective taking, operate within different power positions, and work with expert and non-expert stakeholders involved in ASGM
Attitudes	Willingness to work with expert and non-expert stakeholders along the ASGM lifecycle Willingness to open up engineering decision making to a variety of stakeholder perspectives	Willingness to work with different ASGM perspectives in different countries and engineering faculty from different countries	Willingness to ensure that sociotechnical innovations/ design projects comply with legal and other regulatory standards relevant to ASGM	Willingness and desire to engage in perspective-taking Willingness and desire to work with expert and non-expert perspectives during project and after graduation Willingness and desire to use engineering to serve underprivileged populations Confidence in being able to make positive changes in communities through engineering

The goal of this framework is to strike a balance between providing guidance for a wide variety of contexts while allowing enough flexibility for projects to reflect local desires, concerns, and needs rather than presuming that these are universal.

Table 1 summarizes our understanding of global sociotechnical competency for engineering students: 1) the content dimensions of Jesiek et al.'s (2014) global engineering competency (technical, cultural, and normative); 2) the desired learning outcomes of knowledge, skills, and attitudes; 3) attention to sociotechnical coordination; and 4) the socially responsible engineering framework.

Project Description: Sociotechnical student learning experiences

Our research builds on previous work by engineering educators to enhance students' sociotechnical thinking. These are growing and range from creating new courses, such as "drones for good" (Hoople & Choi-Fitzpatrick, 2020), to integrating sociotechnical perspectives into existing courses required for students' majors (Andrade & Tomblin, 2018, 2019; Blacklock et al. 2021; Claussen & Smith, 2019; Johnson et al., 2019; Leydens et al, 2018; Smith et al, 2017; Smith et al., 2019, 2020). Leydens' and Lucena's book *Engineering Justice* (2017) offers a systematic approach for making visible the inherent social justice dimensions of engineering in classes, design projects, programs, and campuses. Blacklock, Claussen, Johnson, and Leydens assess the sociotechnical integration efforts they lead in engineering courses (Blacklock et al., 2021; Claussen et al., 2021; Johnson et al., 2019; Leydens et al., 2018). Their findings point to the significance of rich discussions for enhancing student engagement, which in turn lead to increased receptivity to sociotechnical thinking; the challenges of moving students to engage with open-ended, ambiguous problems; and the importance of learning from others and sharing knowledge (Blacklock et al., 2021).

Our project departs both structurally and theoretically from the existing research on sociotechnical integration. It involved a relatively small number of U.S. undergraduate students (11 in 2019 and eight in 2020) in a summer field-session environment, collaborating with Colombian faculty, students, and community stakeholders. Undergraduate students were enrolled at the Colorado School of Mines (Mines) and the United States Air Force Academy (USAFA), and they were mentored by graduate students from Mines, University of Texas – Arlington, and University of Colorado – Boulder. Colombian faculty and students came from Universidad Nacional de Colombia (UNAL) – Medellín and Uniminuto. We focused these learning opportunities to include a period of summer immersion that laid the foundation for ongoing academic year virtual collaborations among Mines, USAFA, and UNAL. In 2019 the immersive period involved a two-week field session in Colombia, whereas in 2020 it involved fully remote engagement with in-country community members due to COVID-19 travel and safety restrictions. This article focuses on student outcomes from these two summer sessions, though, as explained below, the design projects continued into academic year courses.

One of our central objectives for both summer sessions was to help students recognize the power differentials animating our project, which were multiple and intersecting: between and among U.S. and Colombian faculty and students, who had very different access to resources and networks; between ASGM community stakeholders and university-affiliated project participants; between ASGM community stakeholders, government entities, and the large-scale mining industry; and among ASGM community stakeholders themselves. Faculty and project subject matter experts shared research explaining internal hierarchies in ASGM operations that keep the most vulnerable miners poor, as well as comparisons of how the local Colombian *departamento* (similar to a U.S. state government) regulates ASGM and large-scale mining. Students witnessed those differences firsthand in the field and listened to ASGM community members explain them in their own words. As described below, students also learned about the specific challenges that women miners face in ASGM work. While we alone cannot mitigate widespread political and economic inequities, we selected research and design activities that would support the most vulnerable actors, such as the ore carriers described below.

2019 In-Country Immersion Learning

In 2019, a diverse group of 11 undergraduate engineering students from Mines and USAFA participated in a two-week field session in Colombia, where they had the opportunity to learn side-by-side with Colombian miners, faculty, and students while visiting mine sites and ore processing facilities. The field session facilitated learning in two structures:

- *Classroom activities* with Colombian students and professors on Colombian mining practices, local cultural significance of mining, and local concerns associated with ASGM operations.
- *Field visits* to the towns where miners live and to mines and *entables* (ore processing plants) to observe, listen, and interact directly with the owners, operators, miners and other community members.

During the first week of the two-week field session, students engaged in a series of activities at UNAL. U.S. students learned from Colombian engineering faculty and students about the ASGM sector; participated in a panel discussion with key stakeholders from mining communities and local, departmental, and federal government agencies; and completed a conceptual site model activity designed by U.S. graduate students that underscored the value of learning how people from different disciplinary and personal backgrounds define problems differently. The purpose of the week's activities was to introduce students to the sociotechnical complexities and dynamics of the ASGM sector, as many students had no formal background or education in mining. This week culminated in a trip to a local gold mine on the outskirts of Medellín. Here, students were able to enter a small mine *adit* (a horizontal passage leading into a mine for the purposes of access or drainage) to observe the conditions that miners experience in their daily work. Further, they were able to see how miners processed their ore at an on-site *entable*. Of particular value were the discussions that students had with the miners about their concerns regarding mine safety, process optimization, and environmental protection.

Following university protocols, Mines faculty and students, along with UNAL faculty and students, traveled to Andes, Colombia, a town with a high level of ASGM and coffee farming activity. Over the years, UNAL developed crucial relationships in this area with miners, *entable* workers, local government officials, and other ASGM stakeholders. They achieved this level of trust with ASGM community members by putting their engineering expertise in the service of community problems such as tailings remediation and process water recycling. Their longstanding relationships and participation in the summer session made our students' fieldwork and projects possible. While in Andes, the students had multiple local conversations paired with first-hand observations of the problems and opportunities experienced by miners and other community members (e.g., farmers and local residents). Students posed questions and sought input on the miners' and *entable* owners' concerns and views on which areas of mining and ore processing were most in need of support. This interaction was facilitated by translation support from the partner university, as well as field observations and some students' participation in various mining activities (e.g. carrying ore, walking the mine *adit* and shafts, touring an *entable*).

During these discussions, miners were most vocal concerning their safety within the underground mine operations. In particular, students' field observations highlighted the potential for fatalities, back strain, and slips/trips and falls due to slippery or unstable rock conditions, and use of explosives in a confined environment. While safety was also important to the *entable* owners and workers in the processing units, here the students heard more problems voiced around environmental concerns, most notably waste materials in close proximity to human and environmental receptors. *Entable* owners and workers expressed that they pay particular attention to environmental issues due to their heightened awareness of the environmental regulatory agency's authority to close their operations, putting their livelihood in jeopardy. The students also met with women miners, who made their living through "mining" the men's waste rock to recover residual gold. The women miners shared their pride in the hard work they undertook and communicated their need to have multiple jobs (mining waste rock and coffee bean harvesting) to provide for their families year-round. Students and faculty observed that all of the stakeholders expressed common needs for good health and environment, as well as good wages and local economies. As part of the daily learning reflections, all students documented what they heard and observed from ASGM community stakeholders on a shared "living map" of the region. The "living map" was a plan view of the community and surrounding area, drawn from experiences and observations the students recounted as part of their daily observations.

The map provided a collaborative visual of identified problems and opportunities for ASGM in the Andes region, serving as a basis for the needs identification of projects in two senior-level undergraduate engineering design courses at Mines. Both design courses were multi-disciplinary and spanned the product development lifecycle from problem identification through product development and testing. The courses enrolled about 50 students each year, including a few students from the intensive summer sessions (three from the 2019 cohort and one from the 2020 cohort). Students in both courses collaborated with UNAL, with the mining professors and undergraduate mining students serving as local resources, providing expert advice, and at times serving as "stage gate" clients for project progression. While these students had fewer opportunities to engage directly with local community members, they were able to take advantage of input from the undergraduate teams who participated in the summer sessions.

In both courses, projects were selected based on input and feedback from the miners and *entable* owners. During the summer session, miners expressed concern with the weight of the ore that they had to carry, as well as discomfort and back pain resulting from the mining process. The majority of miners load and transport the ore in a backpack-like sling called a *catanga*. Additionally, the miners were concerned with the air quality inside the mines; a month prior to our visit, a fatality resulted from poor ventilation of hazardous gases. In both cases, miners and their family members sought assistance on personal safety support. *Entable* owners expressed more concern with the environmental aspects of waste materials. These concerns included the use of mercury or cyanide in processing, the potential for contaminated process water to impact local surface waters, and the large amount of tailings that result from gold processing. For example, when new environmental regulations came into effect, the *departamento*-level regulatory agency shut down an *entable* for releasing materials into adjacent surface waters, but without providing guidance to the owners on how they could safely operate and maintain the livelihoods of mining community members. Based on this direct input from the miners, *entable* operators, family members, and students decided to work on developing a low-cost air sensor, an improved *catanga*, water processing options to address low pH and elevated dissolved metals concentrations, and the reuse of tailings into bricks. Over the duration of the courses, the partner university provided feedback to the students. The students, in turn, provided presentations via translated YouTube videos to the miners and *entable* owners. The miners and operators selected YouTube so that they could view during good Internet times, as well as watch with family members and other community members.

Due to logistical constraints, USAFA students were only able to travel to Colombia for the first week of the summer field session. After returning to the U.S., they participated in a remote field study during the second week where they performed crucial design work on selected projects identified during week one. While this arrangement was not what we had initially desired for this fieldwork experience, it did afford the ability for the project team to explore a distance-based component of the fieldwork experience, which would become even more valuable when the COVID-19 pandemic began later in the year.

Using information gained from their interactions with the diverse Colombian ASGM community stakeholders, the students identified two projects to which they could contribute remotely. The first project explored the optimization of *entable* process water treatment in an effort to: a) increase gold recovery from fine-grained mine tailings, and b) reduce the turbidity (the cloudiness or opacity of a liquid) of process water eventually released to the environment. The second project explored the effects of mining practices and coffee agriculture on a local river. The goal of this work was to explore the intersection between the mining and coffee farming livelihoods and their potentially synergistic effects on the environment. Students began developing a tool to evaluate the impacts of coffee pulp disposal in receiving waters, specifically the potential impact on dissolved oxygen levels and the corresponding potential changes in dissolved mercury.

Students were able to use technical resources available to them in the U.S. to provide support to the larger undergraduate student project team “on the ground” in Colombia. Such resources included technical references (e.g., textbooks, design codes, standards, etc.), library materials (technical literature, government reports, etc.), computing and IT capabilities, laboratories, and design/prototyping spaces. For example, the students working on sedimentation basins needed information on reactor analysis, settling behavior (e.g., Stokes Law), and conventional design standards used in professional practice. This sharing of information was an authentic learning opportunity, given that even licensed professional engineers need to collaborate and consult resources for specialized information. Graduate students facilitated the interactions between the remote students and project partners using a combination of the online platforms WhatsApp and Zoom. This culminated with a preliminary report of findings that students shared with the community members in Andes. This work was then continued as part of a senior-level independent study, which allowed for further development of the project goals. Fortuitously, the lessons learned from this remote experience would become valuable for the following year.

2020 Virtual Field Session

In 2020, the burgeoning COVID-19 pandemic made international fieldwork impossible so RMRC faculty designed a two-week virtual field session for eight participating students that would align with the same learning outcomes as the 2019 session. The session was carefully crafted with international partners to ensure a positive learning experience integrated with our understanding of online teaching and technology platforms. The imbalance of material resources, including access to telecommunications, available to mining communities compared with resources available in the U.S. added complexity to the planning. For 2020, students participated remotely in four main activities on each day of the field session: a) presentations and workshops led by RMRC faculty, graduate students, and project advisory board members; b) a creative capacity building (CCB) workshop led by community facilitators in Colombia; c) collaborative design activities addressing the mining community's needs and desires; and d) verbal and written group and individual reflections on each day's activities.

As in the 2019 session, the 2020 students learned each day from U.S. and Colombian faculty, U.S. and Colombian graduate students, and subject matter experts through presentations and discussions. Those covered topics such as viewing ASGM as a sociotechnical system, problem definition as core to global sociotechnical competency, mercury use in ASGM, interactions between large-scale mining and ASGM, listening and trust building, and the environmental and public health dimensions of ASGM.

Students also participated in the CCB process on a daily basis. The main purpose was for them to learn about how community-driven innovation can provide a pathway for communities to design and implement solutions to local challenges. The virtual CCB workshop was a collaborative effort between C-Innova (Centro de Innovación de Tecnologías Apropiadas y Educación), a Colombian community-based organization dedicated to social innovation; the MIT D-Lab; and the authors. In this work, the U.S. students witnessed how local Colombian facilitators from C-Innova trained ASGM community members on the design cycle based on MIT's D-Lab CCB framework for participatory design. The CCB framework is based on a method of inclusive collaboration where all of the involved stakeholders progress through the design process to self-identify locally significant challenges and approaches to addressing them – a crucial need for the

ASGM sector (Smits et al., 2020). The CCB design process spans project definition through prototyping. The pandemic offered the opportunity to adapt the original in-person CCB framework to a virtual format while specifically addressing key educational and technological limitations of the mining communities. For our field session, D-Lab and C-Innova adapted their in-person CCB model to a completely virtual format, consisting of recorded instructional videos and WhatsApp group texts.

Before our summer session began, MIT D-Lab and C-Innova led problem-identification workshops in Andes. As the focus of the CCB process is to assist communities to design solutions to the challenges they face, the community concerns were widely different in 2020 due to the COVID-19 pandemic. Miners identified their primary needs to be protecting their health and securing their food supply, as the pandemic had disrupted supply chains for food and materials. Through the CCB process, miners identified, designed, and prototyped personal protective equipment, home gardens, and chicken coops. RMRC students met on Zoom and WhatsApp to observe and sometimes participate in the CCB, including the teaching and learning of the design cycle and the building of the artifacts using locally available resources. During the workshop, students – each working from home – interacted with miners, with each other, and with facilitators. At the end of every daily workshop session, students debriefed with the Colombian facilitators about the process of participatory design and wrote answers to reflection prompts developed by project faculty.

In 2020, the CCB projects related to COVID-19 that were identified by the community members did not closely align with the students' areas of expertise. Therefore, students leveraged the sociotechnical skills and shifted mindsets they developed in the CCB to further advance three of the projects that originally emerged from the 2019 field session: back health of miners carrying ore out of mineshafts, remediation/reuse of tailings for conversion into construction materials, and water reuse/recirculation inside of gold processing plants. Subsequently, these projects were adopted in 2020-2021 undergraduate design classes, where incoming cohorts continued to work on their development during the academic year. Similar to 2019-2020, the 2020-2021 design courses collaborated with the partner university, using YouTube videos to convey information to the Colombian stakeholders. In contrast with 2019, the 2020 students used YouTube videos as an ongoing means of communication throughout the course, not just as a final presentation. Students provided design drawings, construction videos, and tutorials on operation and maintenance as the final project deliverables. In the 2021-2022 academic year, students continued to work on providing fully tested prototype designs to the participating ASGM Colombian stakeholders for their use, modification, and/or termination.

Two things became clear as we observed students in the virtual learning environment. In terms of student understanding of the problem/opportunity, the students were more engaged with community members and their problems/opportunities when they were able to directly "see" or "feel" the problem. In 2019, these observations and feedback were obtained when wearing a *catanga* and feeling the weight and load distribution on a person's back; walking through hazardous and steep terrain in order to arrive at a mine site; and witnessing the close proximity of the *entables* to rivers, homes, and coffee agricultural areas. In 2020, the students experienced these things vicariously. One of the most engaging moments for their learning was when they observed, on Zoom, a miner putting on the *catanga* and hearing him share his experience with using the device. We also observed that in the virtual learning environment, the students had a much stronger relationship with (and reliance on) the graduate students and faculty for information, feedback, and guidance, which led to a stronger technical focus for their learning. These observations help provide context for the formal assessment of students' knowledge, skills, and attitudes as a part of our engineering education research.

Research Methods

Data collection

Our educational research followed nearly identical protocols during both summer field sessions, despite the different formats of the sessions. Students completed the same set of assessment exercises, once at the beginning and once at the end of the summer session, allowing us to compare the influence of the summer session on their knowledge, skills, and attitudes. Teaching and learning assessment experts at Mines Center for Teaching and Learning vetted these assessment exercises. Given the relatively small number of students in our project, we used multiple research methods to provide a richer sense of their learning experiences, as detailed here.

One-on-one structured interviews were conducted with students by members of the project faculty or staff. The interviews asked the students four questions in the context of ASGM at our field site:

1. Who would you engage (observe, talk with, consult, ask questions to, etc.) to begin defining problems associated with gold mining and processing? List as many people or types of people as you can.
2. What kinds of questions would you ask these people in order for you to understand how the problems you defined are interlinked with other places, other actors, and other areas in the gold supply chain?
3. How would you engage the stakeholders you identified in question #1 to begin solving problems associated with gold processing?
4. What kinds of questions would you ask (whom?) to understand if these problems could have different solutions if the context changed, for example, if other resources or opportunities became available?

In 2019, pre- and post-session interviews were conducted in person, whereas in 2020 all interviews occurred via Zoom.

A writing exercise was assigned, in which students responded to the following prompts:

1. What do you think are the biggest challenges related to artisanal and small-scale gold mining (ASGM) in Andes, Colombia?
2. What do you think the miners in Andes would identify as the biggest challenges related to their work?

3. What should be the desired outcomes of interventions to make ASGM more sustainable in Andes? Prioritize them in a list.
4. How do you think miners in Andes would identify and prioritize the desired outcomes of interventions to make ASGM more sustainable?
5. Who are the key stakeholders related to ASGM in Andes? Create a list of how you would prioritize them in the process of co-design.
6. Provide one example of a "solution" for ASGM challenges that is appropriate for the local context of Andes. Explain why it is appropriate to this specific historical, cultural, economic, and physical context.

A survey (available in Appendix A) was developed and deployed to gauge students' a) ability to engage in perspective-taking; b) desire to learn from people with different backgrounds; c) desire to pursue engineering careers that involved humanitarian work and work outside of the U.S.; d) personal and professional self-efficacy; and e) sense of fulfilment in engineering. The survey questions were derived from previously validated instruments: one assessing engineering students' global competency (Downey et al., 2006), one measuring empathy (Gerdes et al., 2011), and one that assessed students' sense of their agency and belongingness in engineering (Verdín et al., 2021).

The Human Subjects Research Team at Mines reviewed the engineering education research and assigned it an IRB exemption given the research design. All faculty and graduate students completed the required human subjects training, and all research participants (including the miners in Colombia) provided informed consent. All undergraduate students who participated in the educational research provided informed consent, and their essays, interviews, and survey responses were de-identified in our records.

Data analysis

We analyzed the data in three phases. Our approach is based in grounded theory, in which hypotheses and theories emerge from the data themselves, through a period of open coding (Case & Light, 2011). In this article, we only analyze data from students who completed both the pre- and post-session responses. Unfortunately, due to difficulties with travel and the pandemic, not all participants completed pre- and post-session surveys, essays, and interviews. For the 2019 cohort, all 11 students completed the interviews, but only five completed the post-session survey and essay. For the 2020 cohort, only four of the eight students completed all pre- and post-session assignments.

First, the essays and interviews were analyzed by Rivera, Smith, and Lucena for student-by-student change in *how they identified and proposed to engage relevant stakeholders*. Question 1 of the interviews asked, "Who would you engage (observe, talk with, consult, ask questions to etc.) to begin defining problems associated with gold mining and processing?" As we read the responses, we identified seven categories of stakeholders that emerged from the student responses: 1) people who make a living from mining, 2) other residents of the mining community, 3) people along the gold supply chain, 4) government, 5) professional experts, 6) public health experts, and 7) other. We completed an initial read-through of each participant, assembled the final seven categories, and discussed our rationale for assigning codes in order to enhance inter-coder reliability (O'Connor &

Joffee, 2020). Rivera then read each essay to code for each of the seven categories. Potentially ambiguous materials were assigned codes following collective discussion. For each student, Rivera created a pre- and post-session map that visually demonstrated changes in their understanding of stakeholders. She made note of the students who had the largest increases in stakeholders listed, the largest decreases, and the participants whose lists stayed relatively the same. We then analyzed student responses to interview questions 2 and 3, which asked about stakeholder engagement, in a similar manner, allowing the categories to emerge from the student responses themselves. We created three broad areas: themes/topics they would include as a part of stakeholder engagement, the kinds of questions they would ask stakeholders, and the methods or platforms used to ask the questions (open-ended interviews, surveys, WhatsApp conversations, etc.). For each area, we created and applied a code list.

Second, we sought to analyze *changes in the students' ability to conceptualize ASGM engineering solutions as inherently sociotechnical in nature*. We were particularly interested in assessing the complexity of students' sociotechnical thinking. While many engineering educators consider an acknowledgement of a social, political, or economic dimension of engineering to qualify as sociotechnical thinking, as summarized above, this definition does not reflect the more robust sociotechnical approach from STS: recognizing that the technical is always already inherently social and vice versa. Acknowledging that there are social dimensions of engineering and that these can influence each other actually leaves the categories of social and technical firmly in place, even if educators intend to do the opposite. We therefore created a scale to assess the complexity of sociotechnical thinking and used it to code student interview responses and essays:

1. Recognition that engineering has both social and technical dimensions.
2. Recognition that the social and technical dimensions of engineering influence each other.
3. A social analysis of a technical issue.
4. Recognition that the social and technical dimensions of engineering necessarily imply and co-constitute each other: what appears to be technical is actually always social, and vice versa.

This scale is represented below, in Figure 1. As illustrated, Type 1 treats the social and technical dimensions as separate entities, while Type 2 allows these two dimensions to affect each other. Type 3 recognizes the technical dimension of a problem as a subset of the larger social dimension, while in Type 4 the social and technical dimensions co-constitute each other.

Third, we analyzed student survey responses to Likert-scale questions, which covered their *self-reported empathy and perspective-taking abilities; desire and ability to integrate social concerns into their engineering decision-making; desire and ability to work with people from different backgrounds; broader career goals; self-efficacy; and views of engineering*. We conducted a paired analysis of each student's pre- and post-session responses and then calculated each cohort's pre- and post-session average for each question.

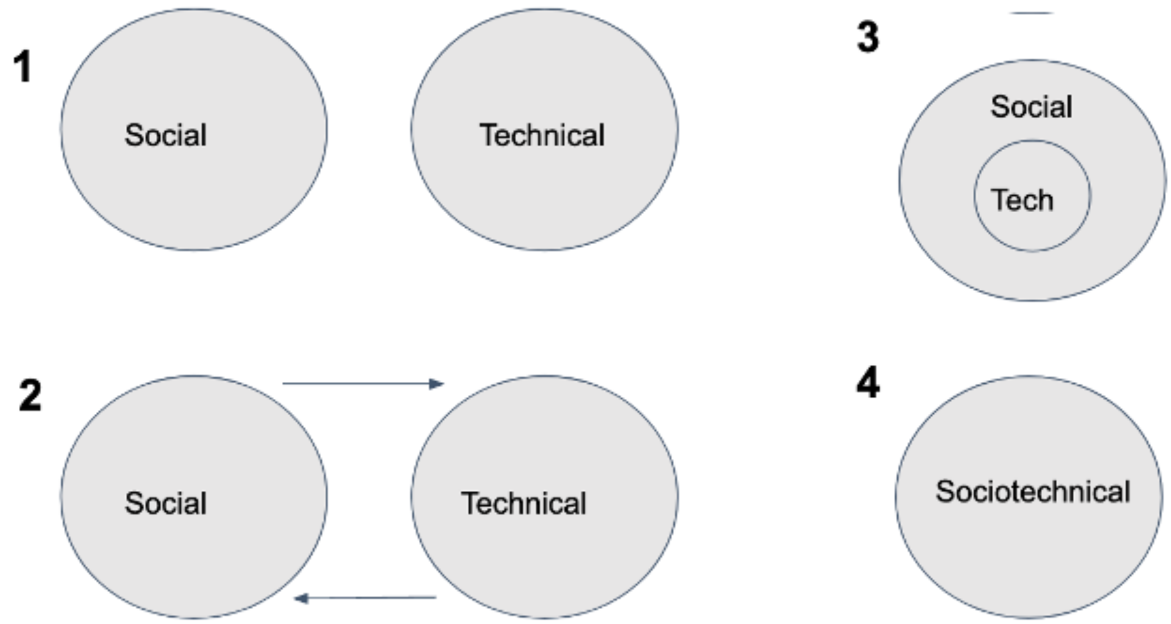

Figure 1. Types of sociotechnical analysis from least complex (1) to most complex (4).

Potential limitations

As with all research, there are limitations to our study. A relatively small number of students (19) participated. In addition to the different formats (in-person versus virtual), the two student groups were themselves different. In 2019, seven men and four women gave informed consent to participate in the educational research, and all but one identified as White. In 2020, six women and two men gave informed consent, and all but one identified as White. While the gender representation in our project is better than our individual institutions as a whole, our student pool lacked racial and ethnic diversity. In terms of disciplinary diversity, both groups included a large number of civil and environmental engineering students. The 2019 cohort also included a chemical engineer and a geological engineer, while the 2020 cohort also included electrical, mechanical, metallurgical, and geological engineers.

The students also received slightly different preparation for the session. The USAFA students involved in the project took an introductory, three-credit hour humanitarian engineering course prior to participating in this project and then some took an independent study after the summer session, which allowed them to concretize their understanding of sociotechnical systems by working on an actual sociotechnical problem. Before the 2019 field session, Mines students all took a specialized elective course analyzing the ASGM supply chain from a sociotechnical perspective. Before the 2020 field session, Mines students all took an upper-division community-based, social science research methods course. Though the content of the 2019 (sociotechnical analysis) and 2020 (research methods) courses were different, they were both taught by the same professor (Lucena). Despite these differences, the 2019 and 2020 students at Mines were all enrolled in our Humanitarian Engineering minor program, which educates engineering students to promote sustainable community development and social responsibility. Many of them also shared a professional and social network through their participation as HE ambassadors.

Finally, the data themselves are limited because the faculty interviewers did not invite students to elaborate on their answers. We created the four-question protocol above to ensure uniformity across the interviews, but this meant that students who gave short answers were not encouraged to build upon them. It is possible (and likely) that students knew or thought more than they shared verbally.

Results

Sociotechnical Coordination

For the purposes of analytic clarity, we focus on a few key dimensions of the global sociotechnical competency framework proposed in Table 1. Sociotechnical coordination undergirds our global sociotechnical competency framework and is highlighted in the criteria that students understand ASGM as a sociotechnical system and be willing and able to identify diverse stakeholders and mediate among their interest. The data from 2019 and 2020 were analyzed for changes in sociotechnical competency using the scale outlined in Figure 1. Table 2 shows a range of student explanations of what kinds of questions they would ask stakeholders. A majority of the students increased the complexity of their sociotechnical analysis from at least one (identifying social and technical contexts) to two (noting how those contexts affect each other).

For instance, participant 12 recognizes that a technical decision – choosing mercury over cyanide – can be viewed as an inherently social decision influenced by a multitude of factors (level four). Their pre-session response is narrowly technical, while their post-session response recognizes a socially, environmentally, and technically concrete decision between mercury and cyanide. This is a more robust approach to sociotechnical thinking than Participant 19, for example, who instead frames social and political concerns as “effects” or “implications” of technical activities (level two), which was the same level as the pre-session interview. Only Participant 1 showed a decrease on our scale, beginning the session focusing on how mining and non-mining activities effect each other (two) but ending without referencing interconnections or mutual influence (one). Among all the students, the most common score we assigned was two. The scores of a small number of students, such as Participant 5, remained stable. Only three of the 19 students reached level four, and we note that they all participated in the virtual 2020 session.

Table 2. Questions posed by students (sociotechnical score in parentheses)

Participant (year)	PRE	POST
1 (2019)	"So how the work they do affect their other normal day lives their real life, not their work life" (2)	"...I'd make sure to ask about themselves, but also how they feel about certain other types of groups..." (1)
5 (2019)	"...see how [miners] view relationships with [famers] and they see how they think maybe [farmers] impact them and then maybe more directly asking how they see something like farming and mining working together or how they interact ..." (2)	"...ask about what they see as how other industries affect their industry...Asking what they like about their work and I didn't realize the intersectionality of the workers before so asking how their jobs compared to previous jobs..." (2)
9 (2019)	"...what challenges and problems they see related to mining...mostly to gain their understanding of what they see as issues" (1)	"...I would start asking questions about the experience both in mining and what they see as well as their experience in the community, how people view them..." (2)
12 (2020)	"...step me through their process of either separating the gold or whatever they daily routines may look like" (1)	"Or what is your process behind choosing mercury over cyanide or something like that, trying to give them the opportunity to come to their own answers..." (4)
13 (2020)	"...discussing the problem that I defined with them...could you describe people who you think that might be affected by this problem?" (2)	"...start off by asking them to define the problem, to tell us how they perceive the problem being in their lives and in their communities. And then once you've defined your problem, bringing that back to them and asking them, how does this make you feel?" (4)
19 (2020)	"Ask questions about past, present, and future - what are you trying to achieve, personal life intersection with the project" (2)	"I would ask them about the social implications of the project. I would ask them about the political affects because I never really considered that before this project and just how prevalent they are" (2)

Stakeholders

Being willing and able to identify and work with diverse stakeholders appears throughout our global sociotechnical competency framework (Table 1). Sixty-one percent of our total students identified more stakeholders at the end of the session than at the beginning. Of those students, the average increase was 3.5 additional stakeholders, though there was a wide range from the student with the largest increase (+10) to three students who just increased by one each. Participant 16 from the 2020 session showed the greatest improvement, listing eight stakeholders in five categories before the summer session but 18 stakeholders in all of the seven categories after the session (Figure 2).

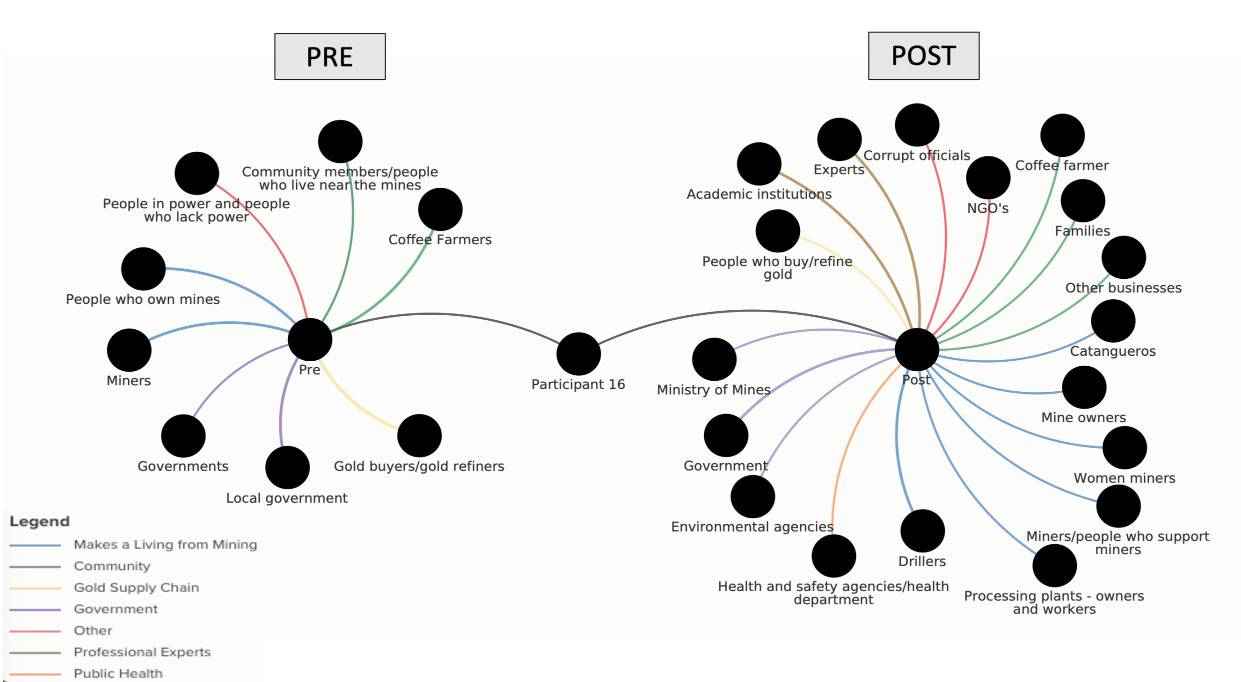

Figure 2. Participant 16's stakeholder map, pre-session (left) and post-session (right) Stakeholders identified in both the pre and post research materials are in the middle.

Not only did students identify more stakeholders, but there was a higher level of sophistication and understanding within the stakeholder categories, as suggested by the increase of detail in the students' responses. Table 3 shows how Participant 5 changed the language they used from "people who study the environment" to the Colombian environmental government agency. Similarly, Participant 16 ends the session being able to identify hierarchies among miners and specific government agencies.

When comparing 2019 and 2020, we found more substantial increases in the 2020 session. This could have been due to the virtual nature of the 2020 field session, which allowed easier access to stakeholders for some students. It could also be that although the students interacted with fewer stakeholders in 2020, they had deeper and more time-intensive interactions with those they did meet.

Self-reported ability and attitudes

We complemented the interview and essay data with a survey that assessed changes in students' self-identified confidence and desire to work with diverse stakeholders, particularly to integrate stakeholder concerns into their engineering practice. Because of the relatively small number of students who participated in the session and provided informed consent, we interpret these data from a more descriptive perspective rather than drawing conclusions from small quantitative differences.

Table 3. Pre- and post-session responses for participant 5 and participant 16

Participant 5 (2019)		**Participant 16 (2020)**	
Pre	**Post**	**Pre**	**Post**
"...potentially other local industries like coffee or farming..."	"...communities that are a part of surrounding businesses like farming or fishing, especially coffee"	"...probably include the miners..."	"..the miners, but even within the miners, there's a hierarchy and there's different miners."
"..maybe officials or people who regulate."	"...*Entable* workers and owners to see what they think about the profession."	"...pay attention to power structure...interview both people who are in power and people who lack power."	"...the processing plants and everybody within the processing plants too."
"...people who study the environment..."	"...definitely *Corantioquia*...to see what their thoughts are on mining and regulations..."	"...governments..."	"...the government and any like health and safety and environmental agencies within the government would be very important because they would have a bigger overall perspective of how these small things fit together."

Both the in-person and virtual students' self-reported answers suggest increased comfort and confidence in working with people and engineering students from backgrounds different from their own (Questions 2 and 8), as well as increased enjoyment learning from professors with backgrounds different from their own (Question 9). This suggests that virtual formats can be effective for achieving these outcomes. However, neither group of students showed evidence of changes in their levels of confidence talking with the people who will be affected by their engineering design projects (Question 5), suggesting that this remains a struggle for engineering students with narrow technical education. Nor did either group report increased desires to integrate the concerns of potential users into their design projects (Question 6), but this may be because Question 6 received the highest scores in both the pre- and post-session surveys, suggesting that our project drew students who already cared about this crucial facet of engineering work.

Table 4. Average pre- and post-session responses for students who completed the survey (2019: 5 students, 2020: 4 students), by cohort and survey category. See Appendix A for survey questions.

		Averages	Question 1	Question 2	Question 3	Question 4
Empathy & perspective taking	**2019**	Pre	4.90	4.50	4.40	4.40
		Post	5.00	4.80	4.80	4.20
	2020	Pre	5.00	4.00	4.86	4.43
		Post	5.00	4.20	4.80	4.00
			Question 5	**Question 6**	**Question 7**	
Integrating social concerns	**2019**	Pre	4.40	4.90	4.20	
		Post	4.40	5.00	4.40	
	2020	Pre	4.00	5.00	4.71	
		Post	4.00	5.00	4.40	
			Question 8	**Question 9**		
Working with people from diff backgrounds	**2019**	Pre	4.50	4.80		
		Post	4.80	5.00		
	2020	Pre	4.29	4.71		
		Post	4.40	4.80		
			Question 10	**Question 11**		
Broader career goals	**2019**	Pre	4.80	4.30		
		Post	4.60	5.00		
	2020	Pre	4.57	4.71		
		Post	4.60	4.60		
			Question 12			
Self-efficacy	**2019**	Pre	3.40			
		Post	3.60			
	2020	Pre	3.29			
		Post	3.80			
			Question 13	**Question 14**		
Views of engineering	**2019**	Pre	4.30	4.40		
		Post	4.00	4.00		
	2020	Pre	3.29	4.14		
		Post	3.80	4.40		

The in-person (2019) students ended the session scoring themselves higher in their enjoyment in asking people questions about their experiences (Question 3) and feeling confident in integrating perspectives from non-engineers in their design projects (Question 7), possibly because they had first-hand, unmediated experience doing this while they were in Colombia. The in-person students also scored themselves higher for desiring a career that allowed them to serve under-privileged populations (Question 11), reaching a 5.0 average in the post-session in comparison with a 4.30 in the pre-session. In contrast, the virtual (2020) students decreased slightly from an average of 4.71 to 4.60 on that question. This raises concerns for us, given that most engineers have few opportunities to engage in the kinds of hands-on work experienced by the 2019 students; in a sense, the 2020 virtual experience resonates more with the actual realities of most engineers' day-to-day work.

We also found some surprising results. Both groups scored themselves low in their confidence in their abilities as an engineer (Question 12), with all average responses falling in the 3.0 to 4.0 range, whereas almost all of the other questions had averages in the 4.0 to 5.0 range. In future work, we are curious to learn whether this holds true for engineering students in general, or if there is a relationship between students' desires to pursue socially-oriented engineering careers and their perceptions of being a "good" engineer, as it is narrowly technically defined in the mainstream. We were also surprised to find that the virtual (2020) students reported increases in their finding of fulfillment in engineering (Question 13) and sense of being able to make positive changes in communities through engineering (Question 14), whereas the in-person (2019) students reported decreases in their responses to those questions. There could be many reasons for this difference. For instance, the in-person students had fewer opportunities to do engineering design work during the session and far more opportunities to see the limitations of engineers' agency to confront the structural dimensions of poverty and the entrenched challenges facing the communities they sought to serve. It is also possible that in-person community service experiences have a negative effect for retention of students in general and women in particular, as students begin to realize the limitations of engineering in solving deep-rooted problems like poverty (Zarske et al. 2012).

Discussion and Conclusion

What does our experience adapting an in-person international field session to a virtual format suggest for educating the next generation of socially responsible engineers? There are some bright spots. First, we examined students' identification of stakeholders for changes in sophistication of detail as well as the number of stakeholders and categories identified. Our data suggest that a majority of all participants (61%) increased their sophistication in identifying and understanding stakeholders. Second, we used a coding scheme to analyze student interviews for any evidence of a refinement in sociotechnical thinking about ASGM. A majority of our students demonstrated greater complexity at the conclusion of the session, and all of those who achieved the highest level in our coding scheme were from the virtual 2020 session. Our research therefore suggests that virtual sessions can still be meaningful for developing students' global sociotechnical competency, though our small student pool cautions against generalizations.

Our project makes clear the utility of mixed-methods research, especially for projects with relatively small numbers of students. The survey data point to the relative differences in student responses by question. For example, students scored themselves much higher in their *desires* to learn about unfamiliar people and places and their desires to integrate stakeholder concerns into their design projects than their *confidence* in doing so. The small number of students does not, however, merit making close distinctions in the numeric scores (between 4.2 and 4.4 averages, for example), and the survey would be improved by adding additional questions for each category that would facilitate comparison with other studies. The interviews and essays were more useful for fine-grained analysis, despite the rigidity of the four-question format we designed to facilitate uniformity across different faculty interviewers. Seeing the limitations of the format, we assigned one graduate student to interview all of the undergraduates in the 2021 session, so that she could invite the students to expand on their answers in a uniform way. The small number of student participants in the sessions made it impossible to identify trends by demographic categories as we had originally hoped. Finally, our project also raises the question of how to incentivize student participation in research in the midst of a very time- and energy-intensive summer session. We suspect that the students who did not complete the post-session interviews, surveys, and essays were simply exhausted from very long and draining days, either in the field or in front of a screen. It would be wise to find ways of assessing the session activities themselves, rather than asking students to complete additional work.

In the research materials we collected, we were disappointed that we did not find stronger evidence of improvements in students' sociotechnical coordination in general. In part, we can attribute this to a lack of faculty and graduate student consensus about the meaning of the term sociotechnical, which reflects a broader lack of definitional clarity in the field of engineering education. It is easy for faculty as well as students to fall into the most common second form we identify, which treats the social and technical as separate domains that influence each other. In the summer 2021 session, we aimed to rectify this by training faculty, graduate, and undergraduate students on the most robust form of sociotechnical analysis – viewing the technical as social and vice versa – and look forward to analyzing those data in future work. We were also surprised that the largest improvements in sociotechnical analysis took place in 2020, as the 2019 students had taken a course that used STS concepts to theorize the ASGM supply chain as a sociotechnical one, whereas the 2020 students took a more general methods class instead. This result could be because the 2019 session leaders did not take each day's debriefing opportunities to connect the intense field experiences with the concepts they had learned in class the previous semester. In 2021, we took greater care to reinforce linkages between STS concepts and field experiences. We also note that we biased the 2020 session towards more academic content (such as faculty and advisory board presentations) because we were not in the field, so it is possible that these focused more on sociotechnical coordination than in the previous year.

A valuable contribution of future research would be further exploring the connection between global sociotechnical competency and students' development of engineering identities. For example, Zarske et al. (2012, 2020) indicate the important role that service-learning courses play in engineering students' perceived skills, professional development, and willingness to continue in engineering. Additionally, Siniawski et al. (2021) show the impact of service-learning projects on technical and professional engineering confidence. Our students' survey responses depart from their findings, raising key questions. It is possible that the relatively small number of students who responded to our survey (five in 2019 and four in 2020) were outliers in a wider field of engineering students. It is possible that our survey questions were not effective in accurately gauging students' confidence, and that the students would have responded differently to the questions from the other studies. It is possible that sociotechnical thinking challenges students' engineering identities (Claussen et al., 2021). Finally, it is also possible that the close engagement with Colombian faculty, students, and mining stakeholders drew attention to the structural causes of poverty, thus emphasizing the difficulties of solving entrenched inequities through engineering. We see a great need to explore further what specific features of service learning promote confidence for diverse engineering students.

While we adapted the format of our field session because of the COVID-19 pandemic, we conclude by suggesting that there may be good reason to use a virtual format even when travel restrictions ease, making the significance of this and related research more enduring. International travel for U.S.-based students and faculty is extremely expensive, and engineering educators have already questioned the extent to which such activities benefit students rather than community members (LaPorte et al, 2017; Leydens & Lucena, 2017; Lucena et al., 2010). We hope that the lessons we and others have learned through the pandemic continue to raise larger questions about how to make humanitarian engineering more equitable.

Acknowledgments

This work was supported by the National Science Foundation under Project Award No. NSF-1743749. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. Further, the views expressed herein are those of the authors and not necessarily those of the U.S. Air Force Academy, the U.S. Air Force, the Department of Defense, or the U.S. Government. The authors would like to acknowledge Professor Oscar Restrepo Baena (Universidad Nacional de Colombia) for his tireless work hosting our team, opening doors for us in the field, managing complex fieldwork relationships, and connecting our students with his own; Libby McDonald (MIT D-Lab) for advising many of our students and carrying forward activities to empower ASGM miners, especially women; Diana Duarte, Alex Freese, and Maria Margarita Gamarra (Diversa/C-Innova) for modeling respectful engagement of ASGM communities, developing and delivering summer session activities, and mentoring our students during the process; and Julia Roos (Mines) for organizing both the in-person and virtual activities, handling the complex logistics of these events, and serving the best interests of our students in the difficult times of the pandemic.

CRediT Authorship Contribution Statement

Jessica M. Smith*:* Conceptualization; Funding acquisition; Investigation; Methodology; Supervision; Writing - original draft; Writing - review & editing; ***Juan C. Lucena:*** Conceptualization; Funding acquisition; Investigation; Methodology; Project administration; Writing - original draft; Writing - review & editing; ***Angelina Rivera****:* Data curation; Formal analysis; Visualization; Writing - original draft; ***Thomas Phelan****:* Funding acquisition; Investigation; Writing - original draft; Writing - review & editing; ***Kathleen Smits****:* Funding acquisition; Investigation; Writing - original draft; Writing - review & editing; ***Robin Bullock****:* Funding acquisition; Investigation; Writing - original draft.

References

Adams, R., Evangelou, D., English, L., De Figueiredo, A. D., Mousoulides, N., Pawley, A. L., Schiefellite, C., Stevens, R., Svinicki, M., Trenor, J. M., & Wilson, D. M. (2011). Multiple perspectives on engaging future engineers. *Journal of Engineering Education*, *100*(1), 48–88. https://doi.org/10.1002/j.2168-9830.2011.tb00004.x

Andrade, N., & Tomblin, D. (2018). Engineering and sustainability: The challenge of integrating social and ethical issues into a technical course. *Proceedings of the 2018 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/1-2--30402

Andrade, N., & Tomblin, D. (2019). What are they talking about? Depth of engineering student sociotechnical thinking in a technical engineering course. *Proceedings of the 2019 ASEE Annual Conference & Exposition* . https://doi.org/10.18260/1-2--33551

Bijker, W. E. (1997). *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*. Cambridge, MA: MIT Press.

Bijker, W. E., & Law, J. (Eds.). (1992). *Shaping Technology / Building Society: Studies in Sociotechnical Change*. Cambridge, MA: MIT Press.

Blacklock, J., Johnson, K., Cook, R., Plata, N. A., & Claussen, S. (2021). Faculty interpretations of sociotechnical thinking in their classrooms: Techniques for integration. *Proceedings of the 2021 ASEE Virtual Annual Conference & Exposition*. https://peer.asee.org/37181

Case, J. M., & Light, G. (2011). Emerging research methodologies in engineering education research. *Journal of Engineering Education*, *100*(1), 186–210. https://doi.org/10.1002/j.2168-9830.2011.tb00008.x

Cech, E. A. (2013). The (mis)framing of social justice: Why ideologies of depoliticization and meritocracy hinder engineers' ability to think about social injustices. In J. Lucena (Ed.), *Engineering Education for Social Justice. Philosophy of Engineering and Technology*, 67-84. Springer. https://doi.org/10.1007/978-94-007-6350-0_4

Claussen, S., Tsai, J. Y., Johnson, K., Blacklock, J., & Leydens, J. A. (2021). Exploring the nexus between students' perceptions of sociotechnical thinking and construction of their engineering identities. *Proceedings of the 2021 ASEE Virtual Annual Conference & Exposition*. http://peer.asee.org/37155

Claussen, S., & Smith, J. (2019). Incorporation of corporate social responsibility into problem-based learning in a semiconductor device course. *Proceedings of the 2019 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/1-2--32959

Cohen, B., Rossmann, J. S., & Sanford Bernhardt, K. L. (2014). Introducing engineering as a socio-technical process. *Proceedings of the 2014 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/1-2--20699

Colombia. (n.d.). PlanetGOLD. Retrieved June 24, 2021 from https://www.planetgold.org/colombia

Cordy, P., Veiga, M.M., Salih, I., Al-Saadi, S., Console, S., Garcia, O., Mesa, L.A., Velasquez-Lopez, P.C., Roeser, M. (2011). Mercury contamination from artisanal gold mining in Antioquia, Colombia: The world's highest per capita mercury pollution. *Science of The Total Environment*, *410–411*(1), 154–160.

Downey, G. (2005). Are engineers losing control of technology?: From 'problem solving' to 'problem definition and solution' in engineering education. *Chemical Engineering Research and Design*, *83*(6), 583–595. https://doi.org/10.1205/cherd.05095

Downey, G. L., Lucena, J. C., Moskal, B. M., Parkhurst, R., Bigley, T., Hays, C., Jesiek, B. K., Kelly, L., Miller, J., Ruff, S., Lehr, J. L., & Nichols-Belo, A. (2006). The globally competent engineer: Working effectively with people who define problems differently. *Journal of Engineering Education*, *95*(2), 107–122. https://doi.org/10.1002/j.2168-9830.2006.tb00883.x

Esdaile, L. J., & Chalker, J. M. (2018). The mercury problem in artisanal and small-scale gold mining. *Chemistry – A European Journal*, *24*(27), 6905–6916. https://doi.org/10.1002/chem.201704840

Faulkner, W. (2007). "Nuts and bolts and people": Gender-troubled engineering identities. *Social Studies of Science*, *37*(3), 331–356.

Gerdes, K. E., Lietz, C. A., & Segal, E. A. (2011). Measuring empathy in the 21st century: Development of an empathy index rooted in social cognitive neuroscience and social justice. *Social Work Research*, *35*(2), 83–93. https://doi.org/10.1093/swr/35.2.83

Hoople, G. D., & Choi-Fitzpatrick, A. (2020). Drones for good: How to bring sociotechnical thinking into the classroom. *Synthesis Lectures on Engineers, Technology, and Society*, *9*(1), i–148. Morgan and Claypool Publishers. https://doi.org/10.2200/S00984ED1V01Y202001ETS024

Jesiek, B. K., Zhu, Q., Woo, S., Thompson, J., & Mazzurco, A. (2014). Global engineering competency in context: Situations and behaviors. *Online Journal for Global Engineering Education*, *8*(1), 1–14.

Johnson, D. G., & Wetmore, J. M. (2008). *Technology and Society: Building our Sociotechnical Future*. Cambridge, MA: MIT Press.

Johnson, K., Leydens, J. A., Erickson, J., Boll, A. M., Claussen, S., & Moskal, B. M. (2019). Sociotechnical habits of mind: Initial survey results and their formative impact on sociotechnical teaching and learning. *Proceedings of the 2019 ASEE Annual Conference & Exposition* . https://doi.org/10.18260/1-2--33275

Johri, A., & Olds, B. M. (2011). Situated engineering learning: Bridging engineering education research and the learning sciences. *Journal of Engineering Education*, *100*(1), 151–185. https://doi.org/10.1002/j.2168-9830.2011.tb00007.x

Krupczak, J., & Mina, M. (2016). An exercise to promote and assess critical thinking in sociotechnical context. *Proceedings of the 2016 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/p.26586

LaPorte, D., Kim, E., & Smith, J. (2017). Engineering to help communities or students' development? An ethnographic case study of an engineering-to-help student organization. *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship*, *12*(2), 103–117. https://doi.org/10.24908/ijsle.v12i2.6593

Leydens, J. A., & Lucena, J. C. (2017). *Engineering Justice: Transforming Engineering Education and Practice*. Wiley-IEEE Press.

Leydens, J. A., Johnson, K., Claussen, S., Blacklock, J., Moskal, B. M., & Cordova, O. (2018). Measuring change over time in sociotechnical thinking: A survey/validation model for sociotechnical habits of mind. *Proceedings of the 2018 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/1-2--30794

Lucena, J., Schneider, J., & Leydens, J. A. (2010). Engineering and sustainable community development. *Synthesis Lectures on Engineers, Technology, and Society*, *5*(1), 1–230. Morgan and Claypool Publishers. http://www.morganclaypool.com/doi/abs/10.2200/S00247ED1V01Y201001ETS011

O'Connor, C., & Joffe, H. (2020). Intercoder reliability in qualitative research: Debates and practical guidelines. *International Journal of Qualitative Methods*, *19*, 1-13. https://doi.org/10.1177/1609406919899220

Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education*, *45*(1), 1–42. https://doi.org/10.1080/03057260802681839

Siniawski, M., Luca, S. G., Pal, J. S., & Saez, J. A. (2015). Impacts of service-learning projects on the technical and professional engineering confidence of first-year engineering students. *Proceedings of the 2015 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/p.24234

Smith, J. M., & Lucena, J. C. (2020). Socially responsible engineering. In D. Michelfelder & N. Doorn (Eds), *Routledge Handbook of Philosophy of Engineering*, 661-673. New York: Routledge.

Smith, J. M., McClelland, C. J., & Smith, N. M. (2017). Engineering students' views of corporate social responsibility: A case study From petroleum engineering. *Science and Engineering Ethics*, *23*(6), 1775–1790.

Smith, J. M., Rulifson, G., Grady, C. L., Smith, N. M., Battalora, L. A., Sarver, E., McClelland, C. J., Kaunda, R. B., & Holley, E. (2019). Critical approaches to CSR as a strategy to broaden engineering students' views of stakeholders. *Proceedings of the 2019 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/1-2--32567

Smith, J. M., Rulifson, G., Stanton, C., Smith, N. M., Battalora, L. A., Sarver, E., McClelland, C. J., Kaunda, R. B., & Holley, E. (2020). Counteracting the social responsibility slump? Assessing changes in student knowledge and attitudes in mining, petroleum, and electrical engineering. *Proceedings of the 2020 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/1-2--34338

Smits, K. M., McDonald, L., Smith, N. M., Gonzalez, F., Lucena, J., Martinez, G., Restrepo, O. J., & Rosas, S. (2020). Voces mineras: Clarifying the future of artisanal and small-scale mining collaborations. *The Extractive Industries and Society*, *7*(1), 68–72. https://doi.org/10.1016/j.exis.2019.12.003

United Nations Environment Programme. Global mercury partnership. Artisanal and small-Scale gold mining (ASGM) | https://web.unep.org/globalmercurypartnership/our-work/artisanal-and-small-scale-gold-mining-asgm

Verdín, D., Smith, J. M., & Lucena, J. C. (2021). Recognizing the funds of knowledge of first-generation college students in engineering: An instrument development. *Journal of Engineering Education*, *110*(3), 671–699. https://doi.org/10.1002/jee.20410

Zarske, M. S., Reamon, D. T., Bielefeldt, A. R., & Knight, D. W. (2012). Service-based First-year Engineering Projects: Do They Make a Difference? *Proceedings of the*

2012 ASEE Annual Conference & Exposition. 25.1157.1-25.1157.15. https://doi.org/10.18260/1-2--21914

Zarske, M. S., Soltys, M. A., & Kracha, J. (2020). Engagement in Practice: Practicing Empathy in Engineering for the Community Course. *Proceedings of the 2020 ASEE Virtual Annual Conference*. https://doi.org/10.18260/1-2--34537

Appendix A. Student survey

On a scale of 1-5, where 1 = strongly disagree and 5 = strongly agree, how would you agree or disagree with each of the following statements?

Empathy and perspective taking

1. I desire to learn about people and places that are unfamiliar to me.
2. I feel comfortable talking with people who have backgrounds different than my own.
3. I like to ask people questions about their experiences.
4. It is easy for me to see other people's points of view.

Integrating social concerns into engineering

5. I feel confident talking with the people who will be affected by my engineering design projects.
6. I seek to integrate the concerns of potential users into my design projects.
7. I feel confident integrating perspectives from non-engineers into my engineering design projects.

Working with people from different backgrounds

8. I feel confident working with engineering students from different backgrounds than my own.
9. I enjoy learning from professors from backgrounds different than my own.

Broader career goals

10. I would like to study or work outside of the U.S. at some point in my career.
11. I would like a career that allows me to serve underprivileged populations.

Self-efficacy in engineering

12. I am confident in my abilities as an engineer.

Views of engineering

13. I find fulfillment in engineering.
14. I can make positive changes in communities through engineering.