Engagement in Practice Paper: Engineering Students vs. Geological Risk in the Gold Supply Chain: Using Geological Risk in Gold Mining Communities to Overcome Technical Instrumentalism among Engineering Students

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Abstract

Student engineers need both excellent technical training and critical skills to put their training to its best uses. At Colorado School of Mines we are experimenting with a series of learning experiences to help students use their technical skills thoughtfully and overcome technical instrumentalism, which we define as the idea that technical skills alone can solve all the practical problems that they encounter. In these experiences, students work with members of Colombian artisanal and small-scale gold mining (ASGM) communities and Colombian students to address geological hazards that endanger miners. This sequenced set of experiences was designed so that students would engage with communities to better understand the complex social, technical, and environmental risks that miners confront and then propose and, in some cases, develop projects to reduce those risks. In this paper we describe the first two phases of this experience. Further research on this learning experience will be necessary to understand its effects for all parties involved.

Introduction

Engineering students need both excellent technical training and the critical skills to use it effectively and responsibly. In the Humanitarian Engineering (HE) program at Colorado School of Mines, we are experimenting with learning experiences that help students use their technical skills thoughtfully and overcome the idea that technical skills alone can solve all the practical problems that they encounter. Colorado School of Mines faculty have developed one such learning experience with support from the NSF-funded Responsible Mining, Resilient Communities (RMRC) Project and in collaboration with educators, researchers, students, and activists primarily affiliated with a rural campus of Corporación Universaitaria Minuto de Dios (UNIMINUTO) and urban Universidad Nacional (UNAL) in Colombia. This partnership has made a series of activities possible for students, including 1) 400-level project-based HE course in the fall of 2018, 2) a Global Social Innovation Challenge (GSIC) project-based competition run by University of San Diego's Center for Peace and Commerce in the spring of 2019, and 3) a field trip to Colombia with the RMRC Project team in the summer of 2019. In these experiences, undergraduate engineers learned about artisanal and small-scale gold mining (ASGM) in Colombia and the hazards that miners and their communities are exposed to. Students developed knowledge about ASGM activities as diverse as panning for gold in rivers or around deposits of tailings from bigger mines, blasting ore out of alluvial deposits using high-pressure hoses, using explosives to excavate shafts, and digging with backhoes and other earthmoving machines [1]. Miners doing this work can face incredible physical, emotional, and economic dangers, and students were encouraged to develop projects in light of this knowledge.

We conceive of these learning experiences as opportunities to help students become "globally competent engineers" [2] capable of doing work in support of the well-being of ASGM communities and undertaking other efforts related to social justice [3] [4]. Not all approaches to engineering support these outcomes. For example, writing about "engineering mindsets," Donna

Riley suggests that the ways many engineers work to solve problems may serve to reproduce inequities [5]. The mindsets she describes are particularly troublesome when they prevent engineers from taking ideas or perspectives different than their own seriously.

As educators, we are particularly concerned about how privileging their own knowledge and expertise at the expense of others may foreclose opportunities for future engineers to engage meaningfully with stakeholders. In this paper, we will refer to *the stubborn idea that technology or technical knowledge alone can be used to identify and solve real-world problems* as "technical instrumentalism". We use this term to describe the dominant way that engineers may enact engineering mindsets when they conceive of problems as primarily technical, and prioritize technical solutions and/or the utility of technical knowledge to address them even when evidence from community collaborators might suggest otherwise.

In the face of technical instrumentalism, we want to give our students the tools to embrace what we call "contextualism." Designing the educational experiences that we describe in this paper, we worked to help students understand that *real-world problems emerge in social, technical, and environmental contexts* and that *responsible, respectful, and sustainable efforts to ameliorate and solve problems must do so, too.* While we develop the concepts of technical instrumentalism and contextualism as polar opposites for the purposes of our work here, we understand that this is a simplified model. We could represent the diverse ways that our students approach their work differently [6]. Be this as it may, considering students' work in terms of these two perspectives provides a useful conceptual framework for assessing a series of activities.

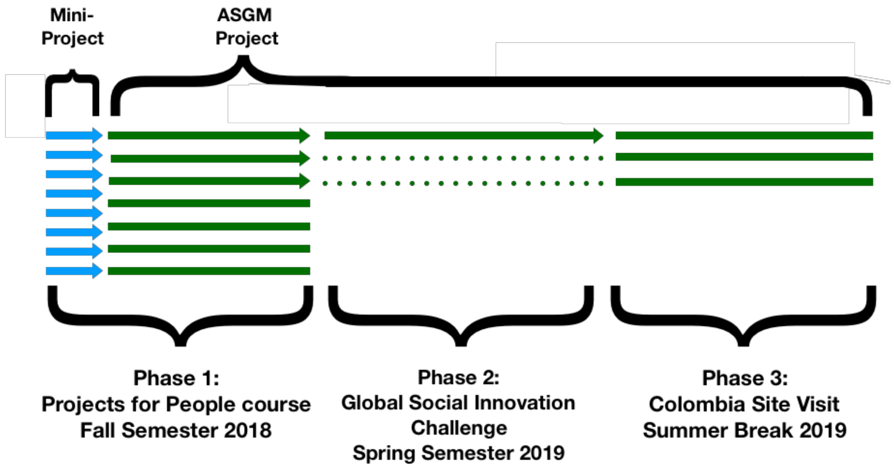
We developed these efforts in light of engineering education research which highlights long-term positive impact that project-based learning can have for student engineers, particularly related to issues like expanding their understanding of global issues, awareness of how decisions affect and are affected by others, and understanding of the connections between technology and society that might be considered to be contextualist forms of engagement [7]. These outcomes are very desirable, but sustaining student motivation and engagement in order to bring them about is by no means simple [8] [9]. Working with community collaborators can help students develop new kinds of insights into engineering and new skills [10] [11] [12] [13], although critics caution that some ways of doing so are more thoughtful and productive than others [14] [15] [16].

Here we offer a preliminary report on our efforts. We give an overview of the results of narrative analysis of two student groups' writing, considering how they wrote about their projects [17], and address their persistence in the year-long educational experience. This paper contributes to ongoing discussion in engineering education about how community engagement can be integrated into coursework. As we show, there is reason to consider students' development of contextualist approaches to engineering in the context of other factors, including students' persistence in an educational experience and their ability to meet their graduation requirements.

A Learning Experience to Promote Contextualism

In a series of learning experiences beginning with 1) a 400-level HE project-based course called "Projects For People" that was offered at Colorado School of Mines in the fall of 2018, 2) a GSIC project-based competition in the spring of 2019, and 3) a RMRC project field trip to be undertaken in the summer of 2019, undergraduate engineering students are collaborating with educators, researchers, students, and activists primarily affiliated with two Colombian universities (UNIMINUTO and UNAL) to design means to mitigate risks related to ASGM.

Figure 1: Flow of Learning Experience



These learning experiences were planned to unfold over three phases (see Figure 1, above). Throughout these phases, students had increasing interactions with partners at UNIMINUTO, UNAL and other members of mining communities. Phase 1 was a 400-level course which met for three hours every Monday evening throughout Fall semester 2018. There, students first formed eight groups to undertake a mini-project on a semi-related topic (in blue), and then reformed into seven groups for a project on ASGM (in green). In the second phase, during Spring semester 2019, these students are developing projects to compete in the GSIC. Some took classes on related topics, and some were even able to make their ASGM work count as a required senior capstone project. Of the original seven teams whose work on ASGM we document here, three began to develop projects in Phase 2. Eventually all but one group dropped out of the GSIC experience. Nonetheless, all three groups will be involved in Phase 3 as students travel to Colombia to engage members of ASGM communities in person.

Context: ASGM and the Complex Risks Associated With It

In 2017, Colombia was among the top 20 gold producing nations of the world, generating over 44 metric tons [18]. Gold mined with ASGM techniques represents a huge proportion of that — by some estimates, ASGM produces 72% of gold [19] and accounts for 87% of gold mining operations in the nation [19] [20]. Miners involved in these efforts often put themselves and their communities in significant danger. ASGM is associated with a wide range of chemical, biological, biomechanical, physical, economic and psychological hazards [21].

The conditions for injury are often produced by environmental conditions like soil structure or rainfall as well as the tools and explosives that people use to mine. However, as many disaster researchers have demonstrated, systemic social issues like poverty and marginalization should also be understood as crucial factors in the affects that a hazard can have [22] [23]. The contextualist implications of this insight are not just matters to be explored in contemporary social science (such as [24] [25] [26]), but actively inform international policy and risk management work [27]. In light of these trends, we understand contexutalist approaches to be a matter of practical importance for our students to learn about. Addressing geohazards related to ASGM in Colombia offers an excellent opportunity for them to do so.

We directed students' attention to the geohazards that can cause miners physical injury through tunnel accidents and landslides [28] [29]. This topic was chosen for a number of reasons, including Phase 1 course instructors' topical expertise and the knowledge of our collaborators at Colorado School of Mines, UNIMINUTO, and UNAL. ASGM is a topic of public discussion in Colombia, but that concern is usually directed at related chemical hazards, particularly the use of mercury in processing [30]. While efforts to manage risk related to ASGM in Colombia have often made reducing mercury use their goal, our Colombian contacts indicated real concerns regarding geohazards and suggested that related risks are being neglected.

Collaborators in the RMRC Project with direct experience on the topic were key allies as we offered these learning experiences. Because many of these people live or work in the state of Antioquia, which produces more gold than any other state in Colombia [31], students learned about ASGM as it is practiced there, particularly in the region of Bajo Cauca and the municipality of Andes. Both are gold-producing and neither are wealthy. Bajo Cauca has the distinction of being both the leading producer of gold in Antioquia and among the poorest places in the nation. In Andes, ASGM is a rapidly emerging industry. The complex environmental and social conditions in both places and our knowledgeable contacts' patience in describing these conditions to our students became the basis for this series of learning experiences.

Phases 1 and 2: "Projects for People" Course and the Global Social Innovation Challenge
All students started the Phase 1 course with a mini-project was designed to give the students the opportunity to experiment with interview techniques, analysis, and writing. Students moved on to a different kind of problem: geological risk related to ASGM in Colombia (see Figure 1). Here, students were tasked with developing proposals to somehow mitigate landslide risk. They were introduced to ASGM in Colombia and the complex social, technical, and environmental conditions that make geological risks possible.

Three groups of students moved from Phase 1 onto Phase 2 and began to further develop their projects for the GSIC. In this international competition, student teams compete to develop viable business plans and meet social innovation goals. These three teams worked closely with Colombian students from UNAL and UNIMINUTO. They were guided by a faculty project manager, and encouraged to take .5 credit mini-courses in the Division of Economics and Business to help them better plan develop deliverables related to this social innovation competition, enroll in a HE seminar focusing on ASGM and community resilience, and find other ways to earn school credit for work related to their projects.

Throughout all phases, crucial information came to these students from reports, peer-reviewed articles, guest lectures by local faculty as well as from video conferencing, text messaging, and emailing with community members. Students had opportunities for both in-class and out-of-class interactions with people who had first-hand knowledge about the topics they were investigating. For example, in the Phase 1 course, faculty hosted a series of two 1-hour-long in-class Skype meetings in class with researchers, activists, and miners based at UNIMINUTO. They also had a 1-hour-long in-class conversation with engineering students and researchers at UNAL. Afterward, students began to communicate directly with their Colombian contacts, managing translation issues with support from faculty when necessary. They were required to interview at least one person as part of their Phase 1 course deliverables, but encouraged to do more. In Phase

2, students had additional opportunities to pursue these interactions. Throughout, we emphasized the importance of treating Colombian contacts as experts with important perspectives and access to information that was not available in articles or reports and, when possible, as collaborators.

Phases 1 and 2: Contextualism and Persistence?

Technical instrumentalism, as we define it, refers to understanding real-world problems as primarily technical, and might be indicated if students 1) prioritize technical solutions to these problems and/or 2) prioritize the utility of their own technical knowledge to address problems. Conversely, contextualist approaches might be indicated if students 1) prioritize non-technical solutions to these problems and/or 2) prioritize the utility of community members' non-technical knowledge to address problems. We evaluated two groups' writing and presentations throughout Phase 1 and Phase 2. We further considered students persistence in Phase 2 and the course credit that students obtained for work on or related to their projects (summarized in Table 1).

Chart 1: Comparing Two Journeys

	Group A				**Group B**			
	Contact with miners	**Course credit**	**Contextualism demonstrated**	**Persistence**	**Contact with miners**	**Course credit**	**Contextualism demonstrated**	**Persistence**
Phase 1	Substantial	1 course (all students)	Substantial	Finished	Some	1 course (all students)	Some	Finished
Phase 2	Substantial	1 course (some students); Sr. Design (some students)	Substantial	Finished	Some	1 course; (some students)	Substantial	Began but did not finish

Group A was highly focused on collaborations with miners throughout the Phase 1 course, and while their technical plans changed, their contextualist orientation was strong from the beginning. Midway through the course, they showcased an understanding of their work as situated in broader social context, writing: *"Risk of physical harm is secondary to financial security, food security…. The team hopes to approach this problem by working with Colombian miners to design and implement a processing program that addresses their concerns..."* In Phases 1, they began to develop a relationship with a processing plant operator in the municipality of Andes. They worked with him to conceptualize and move forward with a plan to process tailings and render them safe to use in construction. In Phase 2, these students lost two group members added two new ones (one of whom was a student at UNIMINUTO). One student in this group enrolled in a seminar related to ASGM, receiving course credit for doing further background research. Two of these students were also able to make their project serve as a a Senior Design project. Because they did so, they were able to receive course credit for their work related to the GSIC and to devote significant time to their project (see Chart 1).

Group B began with what we consider to be instrumentalist proposals in the early parts of the Phase 1 course, writing, for example that they wanted to: *"Implement geological sensors to give early warning signs for geological hazards inside caves and in tailing piles recognized as* *hazardous."* They engaged engineering students at UNAL to identify promising project ideas. However, they were not able to address to the utility of the plan the way that the local activists and former miners at UNIMINUTO could have. This, in turn, impeded students' ability to develop a contextualist project. In Phase 2, these students lost one group member added a new one (a student at UNAL). One student in this group chose to enroll in a seminar related to ASGM (see Chart 1). Group B worked to further define their focus and eventually developed a more contextualist plan for an "emergency toolbox" in conversation with ASGM activists working in Bajo Cauca. However, without a strong working collaboration with an ASGM community member from the start, their project proposals were vaguer. They were not able to obtain as much school credit as Group A did, and they struggled to allocate time and energy to the project.

The differences between these groups' ideas first became evident when instructors from Colorado School of Mines spoke to activists and former miners at UNIMINUTO. These conversations revealed that Group A's proposal was exciting to miners, but that Group B's proposal might not only be uninteresting to miners but might put participants in danger by making officially "illegal" activities visible to authorities and subject to significant economic harms. Although they were making progress toward contextualism, Group B eventually dropped out of Phase 2. They will have further opportunities to develop contextualist approaches when they take part in Phase 3. However, without participation in Phase 2, these are likely to be less developed than Group A's project plans.

Discussion and (Preliminary) Conclusions

In this set of learning experiences, students from Colorado School of Mines engaged with educators, researchers, students, and activists affiliated with UNIMINUTO and UNAL. Although we may not be able to replicate this learning experience, we can use it to consider efforts to help students learn to demonstrate contextualism through projects involving community engagement.

Longer learning experiences may offer students more opportunities to engage with community members and see how real-world problems emerge in social, technical, and environmental contexts and that responsible, respectful, and sustainable efforts to ameliorate and solve problems must do so, too. However, students may have trouble allocating time to participation if these experiences do not allow them to fulfil school requirements. Further, early adoption of contextualist approaches and serious community engagement was related, in the case of Group A, to student persistence in this multi-semester experience and may have been one factor that enabled this group to make participation in Phase 2 count toward other school requirements. It is worth investigating further whether this coincidence is meaningful.

To do so, it will be necessary to evaluate the whole class's work in Phase 1 in more depth, as well as all students' work and experiences through Phases 2 and 3. In further research, we plan to not only consider students' developing projects, but also to work with the Colombian educators, researchers, students, and activists with whom our students have worked in order to understand the effects of this set of learning experiences *contextually* for all parties involved.

References

[1] N. Smith, J. Lucena, J. Smith, O.J. Restrepo Baena, G. Aristizabal, A. Delgado. "A Framework for Research and Education on Artisanal and Small-Scale Mining in Latin America." *Intl Journal of Geosources and Environment,* vol. 4, no. 2, pp. 99-104, 2018.

[2] Downey, G.L., Lucena, J.C. Moskal, B.M., Parkhurst, R., Bigley, L., Hays, C., Jesiek, B.K., Kelly. L., Miller, J., Ruff, S., Lehr, J. and Nicholas-Belo, A."The Globally Competent Engineer: Working Effectively with People who Define Problems Differently." *Journal of Engineering Education,* vol. 95, no. 2, pp. 107-122, 2006.

[3] J. A. Leydens and J. C. Lucena, *Engineering Justice: Transforming Engineering Education and Practice*, Hoboken, NJ: John Wiley and Sons, 2017.

[4] C. Baillie, A. Pawley, and D. Riley (Eds.). *Engineering and Social Justice: In the University and Beyond*, West Lafayette, IN: Purdue University Press, 2012.

[5] D. Riley, *Engineering and Social Justice*, Williston, VT: Morgan and Claypool, 2008.

[6] C. Zoltowski, W. Oakes, and M. Cardella, "Students' Ways of Experiencing Human-Centered Design," *Journal of Engineering Education*, vol. 101, no. 1, pp. 28–59, 2012.

[7] A. C. Heinricher, P. Quinn, R. F. Vaz, and K. J. Rissmiller, "Long-term Impacts of Project-Based Learning in Science and Engineering," *ASEE Annual Conference Proceedings*, Atlanta, GA, 2013.

[8] P. C. Blumenfeld, E. Soloway, R. W. Marx, J. S. Krajcik, M. Guzdial, and A. Palincsar, "Motivating Project-based Learning: Sustaining the Doing, Supporting the Learning," *Educational Psychology*, vol. 26, no. 3–4, pp. 369–398, 1991.

[9] B. J. S. Barron, D. L. Schwartz, N. J. Vye, A. Moore, A. Petrosino, L. Zech, and J. D. Bransford, "Doing with Understanding: Lessons from Research on Problem- and Project-Based Learning," *Journal of the Learning Sciences,* vol. 7, no. 3–4, pp. 271–311, 1998.

[10] E. Coyle, L. H. Jamieson, W. C. Oakes, "Integrating Engineering Education and Community Service: Themes for the Future of Engineering Education*," Journal of Engineering Education*, vol. 95, no. 1, pp. 7– 11, 2006.

[12] M. Lima, W. C. Oakes, and J. L. Gruender. *Service-learning: Engineering in your community*. Wildwood, MO: Great Lakes Press, 2006.

[13] A. Bielefeldt, K. Paterson, and C. Swan, "Measuring the Value Added from Service-Learning in Project-Based Engineering Education," *International Journal of Engineering Education*, vol. 26, no. 3, pp. 535–546, 2010.

[14] J. Schneider, J. A. Leydens, and J. Lucena, "Where is 'Community'?: Engineering Education and Sustainable Community Development," *European Journal of Engineering Education.*, vol. 33, no. 3, pp. 307–319, 2008.

[15] L. Vanasupa and L. Schlemer, "Relational versus Transactional Community Engagement: An Experience of the Benefits and Costs," *ASEE Annual Conference Proceedings*, Indianapolis, IN, 2014.

[16] D. Nieusma and D. Riley, "Designs on Development: Engineering, Globalization, and Social Justice," *Engineering Studies,* vol. 2, no. 1, pp. 29-59, 2010.

[17] Bernard, H. Russell. *Research Methods in Anthropology: Qualitative and Quantitative Approaches* (4th ed.). Maryland: AltaMira Press, p. 416, 2005.

[18] World Gold Council Gold Hub Website: https://www.gold.org/goldhub/data/historical-mine-production [Visited Feb 4 2019]

[19] O. García, M.M. Veiga, P. Cordy, O.E. Suescún, J. M. Molina, and M Roeser. "Artisanal Gold Mining in Antioquia, Colombia: A Successful Case of Mercury Reduction." *Journal of Cleaner Production* vol. 90, pp. 244-252, 2015.

[20] Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development. *Global Trends in Artisanal and Small-Scale Mining (ASM): A Review of Key Numbers and Issues*. Winnipeg: IISD, 2017.

[21] World Health Organization *Artisanal and Small-Scale Gold Mining and Health: Environmental and Occupational Health Hazards Associated With Artisanal and Small-Scale Gold Mining.* Geneva: World Health Organization, 2016.

[22] A. Oliver-Smith, "Anthropological Research on Hazards and Disasters," *Annual Review of Anthropology*, vol. 25, no. 1, pp. 303-328, 1996.

[23] K. J. Tierney, "From the Margins to the Mainstream? Disaster Research at the Crossroads." *Annual Review of Sociology*, vol. 33, no. 1, pp. 503-525, 2007.

[24] R. E. Barrios, "Resilience: A Commentary From the Vantage Point of Anthropology," *Annals of Anthropological Practice* vol. 40, no. 1, pp. 28-38, 2016.

[25] E. Reddy. "The Production of Earthquake Emergencies: Technoscientific Earthquake Early Warning in a Social and Material World," *Revista Iberoamericana de Comunicación* Vol. 30 no. 1, pp 17-44, 2016

[26] M. Tironi, I. Rodriguez-Giralt, and M. Guggenheim, *Disasters and Politics: Materials, Experiments, Preparedness.* West Sussex, UK: Wiley Blackwell/The Sociological Review, 2014.

[27] United Nations International Strategy for Disaster Risk Reduction, *Sendai Framework for Disaster Risk Reduction 2015 - 2030*, World Conference on Disaster Risk Reduction, Sendai, Japan, 2015.

[28] J Hinton. *Communities and Small-scale Mining: An Integrated Review for Development Planning.* Washington (DC): World Bank, 2006.

[29] R. Hentschel and F. Hruschka, *Global Report on Artisanal and Small-Scale Mining*. Geneva: International Labour Organization. 2002.

[30] A. Saldarriaga-Isaza, C. Villegas-Palacio, and S. Arango, "Phasing Out Mercury Through Collective Action in Artisanal Gold Mining: Evidence From a Framed Field Experiment" *Ecological Economies*, vol .120, pp. 406-415, 2015.

[31] Agencia Nacional de Minería Website: https://www.anm.gov.co/ [Visited Feb 4 2019]