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International Interdisciplinary Collaboration: Artisanal and Small Scale Gold Mining and Mercury Contamination in Colombia

***Mateo S. Pimentel* [1]*, *Cristian A. Flórez* [2] *and Oscar Jaime Restrepo Baena* [2]**
School for the Future of Innovation in Society, Arizona State University [1]
Facultad de MInas, Universidad Nacional de Colombia, Sede Medellín [2]
mspiment@asu.edu*

Abstract: *This paper describes key aspects of our experience with international interdisciplinary collaboration. Two Colombian engineers and an American interdisciplinary researcher comprised our team. We formed in response to the mercury contamination crisis coextensive with artisanal and small-scale gold mining (ASGM) in Colombia. Certain elements in the literature on scientific collaboration and interdisciplinarity are visible in our partnership. We discuss them and offer some reflection on the place and value of our experience relative to the literature. Other collaborative research teams might likewise contribute to knowledge construction in this area.*

Keywords: International; Interdisciplinary; Scientific Collaboration; Colombia; Gold Mining; Mercury

Introduction

International interdisciplinary collaboration is a regularly occurring phenomenon. It spans continents, cultures, institutions, disciplines, languages, and is integral to global economics and international relations. The main purpose of this paper is to help answer what this collaboration looks like in practice. To that end we examine and share our experience with the phenomenon. We recognize and discuss specific factors that likely contributed to our success so that others might be encouraged to share also. We present select examples of work projects and outcomes stemming from our 2017 partnership, which we formed in response to the mercury contamination crisis in Colombia. This research problem is economic, political, environmental, technological, social, and such a complex issue deserves, if not demands, an interdisciplinary response.

In Colombia, *Artisanal and Small-scale Gold Mining* (ASGM) boasts 200,000 miners responsible for the production of roughly 30 tons of gold each year. The economic significance is especially important for the north-eastern region of Antioquia, Colombia, where mining precipitates most of the employment. Antioquia houses seventeen towns and some 30,000 miners dedicated to ASGM. Miners transport gold ore to urban processing centers that carry out various phases of amalgamation and burning. These are key to extracting gold, and mercury is often used. During the gold-mercury separation phase mercury emissions release into the environment as vapor. The vapor then gets directly discharged to water sources and soils, causing the toxic methyl mercury contamination of both flora and fauna. The effects impact the lives of thousands of people, whether they have some direct involvement or simply live nearby. Consequently, relative to ASGM, Colombia is the world's largest polluter of mercury per capita.

The social consequences of ASGM draw attention from several disciplines. Illegal or informal mining, normally associated with a number of grave social and environmental impacts, compounds the social need to reduce mercury-use, which affects Colombians in myriad ways. Nearly a dozen companies illegally imported 130 tons of mercury into Colombia in 2009 alone; most of this went to artisanal gold mining. Globally, too, inefficient technologies compound both social and environmental problems arising from mercury-use. Such technologies demand the use of toxic substances during amalgamation and cyanidation, which occur during processes of gold recovery (Cordy et al., 2011). In several sites our team visited in Antioquia the technologies were efficient enough; yet, a source of mercury-related problems remains that miner's process material in the same way. For example, they do not know how the particle size affects gold extraction, or they do not know how to change the equipment operation parameters, or how such parameters affect gold extraction. In the wake of our collaboration we still maintain there is a need to reduce mercury-use in a way that is replicable.

According to the MIT Observatory of Economic Complexity (OEC) Colombia has one of the world's most complex economies. The OEC reports that Colombia is the 53rd largest exporter, and the 47th largest importer, in the world. In recent years Colombia's exports have totaled $56.5 billion, and extractive metallurgy has proven essential to the country's economy. This is especially true of gold ore: the export value of precious metals was $2.07 billion in 2014, with gold comprising 85% of that value. Moreover, gold is Colombia's fifth largest export; coffee only marginally leads precious metals, and gold in particular, as the country's fourth top export. Thus, gold plays a significant financial role for Colombia, which annually exports 63% of its gold (i.e., $1.12 billion) directly to the United States.

The precipitous rise in gold prices since the turn of the century prompted a gold rush many correctly characterize as violent. Several groups (e.g., neo-paramilitary groups, drug-traffickers, guerrillas, etc.) have endeavored to establish control over ASGM operations. They have not declined the use of violence to that end. Ibarra Sanchez (2017) states, "Illegally mined gold is fueling violence as gold has overtaken cocaine as the main source of revenue for armed groups," generating some seven billion dollars annually. At least eighty percent of the gold that is mined in Colombia is done so informally or illegally. Such statistics portend the displacement, forced labor, and sex trafficking of regional denizens, all of which undergirds a burgeoning industry (Beeler, 2016).

That gold and illicit narcotics are interchangeable relative to their ability to sustain illegitimate or criminal networks means additional impacts for those who normally profit from coercive tactics like kidnappings. Field research in Colombian gold mining regions –

including seventy-plus semi-structured interviews and a review of the press (including data from non-governmental organizations, as well as local and regional reports and national media) – indicates the "evolution of the links and interchangeable nature of gold and drugs as conflict resources throughout the production phases of the gold extraction process" is part of the complex relationship between illegitimate actors, their networks, and control of conflict resources in hostile conditions. Academicians and policy- and decision-makers should be mindful of the need to seriously investigate "potential transformations of illicit markets and their role in shaping the prospects of durable peace" (Rettberg and Ortiz-Riomalo, 2016, pp. 82-96).

Our experience with international interdisciplinary collaboration may well indicate that collaborations such as ours have an important place in making transformation and lasting peace a reality. Furthermore, to underscore the significance of such work, and to adequately situate our own contribution, it is important to visit the elements in the literature that follows.

Literature Review

Scientific collaboration promises answers to complex questions and solutions to difficult problems. These can exceed the capacities of lone disciplines (see Klein and Newell, 1997; Klein, 2004). Hence, at times the problem-oriented approach of scientific collaboration necessitates the crossing of disciplinary boundaries. What results, both in terms of knowledge and information, can be complex and immense. Collaborative results may need structuring, as may collaborative contributions (Jeffrey, 2003). Ultimately, though, collaboration promises to solve problems in politics, economics, society, democracy, development, sustainability, culture, and international relations, among others. The breadth of collaborative diversity is additionally evident in the scope of terminology, research epistemologies, and methods voiced by the literature. Collaboration unfolds across universities, industries, science and society, and organizations and institutions of all kinds (Sonnenwald, 2007). A definitive analysis of collaboration is unlikely, however, given the scope of relationships, contributors, and activities involved (Smith, 1958).

Certain aspects of collaboration are well understood and documented, namely those thought to enhance teamwork and productivity. Collaborative work, efficiency, speed, standardization, and so on, all present unique advantages and disadvantages (Bush and Hattery, 1956). Limitations, delays, and strictures, as well as their sources, have been documented. These constitute an important part of the work of scientific collaboration and the production of knowledge, both of which depend on research groups and teamwork (Hackett, 2005). For instance, collaboration and teamwork afford green researchers entree to professional communities. As some seek to advance professionally and to gain recognition collaboration serves as a social regulator for scientific labors. It provides greenhorns access to data, facilities, support, and more. Moreover, collaboration is relevant both scientifically and personally: it allows for "both personal and mundane satisfactions" and also "those provided by 'science for science's sake'" (Beaver and Rosen, 1978, 69). To realize these ends collaborators share datasets, communicate by email, interact at conferences, visit laboratories abroad, share papers, and potentially co-author them (Frame and Carpenter, 1979). Despite what is known further study of collaboration is both anticipated and welcome (Bush and Hattery, 1956).

Interdisciplinary collaboration is one form of scientific collaboration that stands to be better understood. The complex character of interdisciplinary collaboration is not easy to weigh, as some studies have indicated. To know more researchers investigate a range of factors and effects, from communication to physical proximity to social influences. All can stimulate collaboration, which in turn affects productivity and can exceed scientific efforts themselves (Katz and Martin, 1997, 1-5). In part science is increasingly collaborative for this reason; another is that solitary individuals are not responsible for most of the knowledge production today. Hence, some argue research team interactions are vital to a deeper understanding science and scientific activity (Shrum, 2001, 682). A wealth of literature exists and makes possible a good understanding of interdisciplinary research (Carayol and Nguyen Thi, 2005). Yet, interdisciplinary collaboration remains conceptually blurry and knotted at points. Some therefore seek to distinguish interdisciplinary modes of research by knowledge integration, or the scope of knowledge (i.e., interdisciplinarity) used in addressing certain problems (Porter et al., 2008).

The National Academies on Facilitating Interdisciplinary Research (2005) describe interdisciplinarity as an institutional change involving disciplinary and institutional integration. Moreover, students and faculty benefit from flexibility and mobility under this interdisciplinarity: the approach to the problem-solving here is not curbed by disciplinary boundaries but rather organized according to problems and questions that societies face (National Academies; Sá, 2008). The National Academies (2005) have thus defined interdisciplinarity as research that combines epistemology, ontology, methods and methodologies, information, techniques, and theories from at least two disciplines or bodies of specialized knowledge. The point is specifically to create knowledge and to solve problems that are too much for any single discipline or "area of research practice" to address (p.188). Others offer more explicit means of differentiating inter-, multi-, and transdisciplinary, but whatever the possible distinctions, they all comprise a crucial phenomenon in the evolution of science. Collaborations are not only visible manifestations and sources of diversity in science, but also they provide newness and creativity (Zitt, 2005, p. 44).

Collaborations are largely consensual; contributors are not forced to collaborate; nor must contributors submit to hierarchy. Voluntary dedication instead signals "relatively egalitarian relationships," even at high levels of organizational structures, whether among institutions or faculty members (Chompalov, 2002, 765-766). Collaborative work, efficiency, speed, standardization, and so on, presents advantages and disadvantages. Again, limitations, inflexibilities, and delays, as well as their sources, have been documented. Even so the work of scientific collaboration and the production of knowledge regularly depend on the collaboration of research groups who experience scientific collaboration (Hackett, 2005). Also, disciplinary boundaries matter because increasing specialization prompts still greater consideration for the diversity of scientific contributions used to solve complex problems or to understand them (Becher and Trowler, 2001). Without determining what counts as *good* *practice* or how interdisciplinary collaboration output translates into support tools for policy- and decision-making collaboration across disciplines is nearly the norm today (Jeffrey, 2003, 539).

More recent publications visit the significance of scientific activity that transcends international boundaries. They stress the highly collaborative nature of international interdisciplinary collaboration. Communities that host collaboration tend to view it favorably (Sá, 2008), perhaps contributing to the increasing significance and frequency of such work around the world. Moreover, collaboration is comprised of interactions occurring "within a social context among two or more scientists that facilitates the sharing of meaning and completion of tasks with respect to a mutually shared, superordinate goal" (Sonnenwald, 2007, 643-45). These goals are unique, and so are the catalysts for the interdisciplinarity that results. For instance, some believe the disciplinary production of knowledge silos what gets produced, arguing "the disciplinary mode of research production leads to an excessive fragmentation of knowledge." Thus, they propound greater *mobility and anarchy* across disciplines and a "continuing process of assembling and reassembling faculty whose interest intersect on the basis of research problems," an approach with a more "dramatic or 'revolutionary' vision of interdisciplinarity … in which institutions strive for a more complete integration of disciplines, institutions 'without walls,' a high degree of flexibility and mobility for students and faculty, and research efforts that are organized around problems rather than disciplines" (Sá, 2008, 540).

National boundaries do not wall-in this scientific activity, which some believe partly inert to the vicissitudes of political, social, and economic forces. Communication enhances scientific collaboration across borders: the world gets smaller, and its geographic effects on science shrink. Part of global scientific collaboration interdisciplinarity is increasingly important: a failure to adopt interdisciplinarity might curb scientific progress, effectively limiting science's contributions to society (Frame and Carpenter, 1979). Consonant here are observations about the world being a scientific space ever marked by complexity, interdisciplinarity, researchers straddling scientific and technological boundaries, research teams, cross-pollination, and action (Bush and Hattery, 1956). Globally, students of collaboration engage especially with the human dimensions for a reason: were scientific knowledge merely the fruit of impartial researchers lacking in commitment, such knowledge might invite charges of triviality. Even though some consider objective knowledge to be untainted by the opinions and feelings of those who make it others have declared such a notion of objectivity to be trivial due to a deeper question that pivots on precisely "how objective knowledge results in science not despite bias and commitment, but because of them" (Mitroff 1974, 591).

Collaborators normally experience working in close proximity and having in-person or face-to-face encounters (Hackett, 2005). Brown and Duguid (2000) argue for the importance of the physical locus, which they believe vital to what people make of information and why it is important. They claim that "envisioned change will not happen or will not be fruitful until people look beyond the simplicities of information and individuals to the complexities of learning, knowledge, judgment, communities, organizations and institutions" (p. 213).

Despite innovations in information and communications technologies Olson and Olson (2000) contend that "distance and its associated attributes of culture, time zones, geography, and language" bear significantly on people. Simulating in-person interaction among human beings and the "space-time contexts" where they unfold is limited in impact (pp. 140-141).

According to Sonnenwald (2007) the tasks of collaboration involve a level of uncertainty that perhaps exceeds other forms of scientific work. This uncertainty extends to goals and appropriate approaches for achieving them, including the notion that trial and error are integral (p. 645). Klein believes reality itself is "a nexus of interrelated phenomena that are not reducible to a single dimension," and that complex problems "cannot be solved by simply applying new information and tools"—nor are they ever definitively solved. Instead, there must be continuous management. Also, the thing under investigation may not be reducible; instead, the cross-pollination of various perspectives and methods adapted to research goals may ultimately give rise to a more comprehensive, holistic understanding among investigators. Finally, there are many tiers to the research that unfolds: teams may work interdisciplinarily and include various stakeholders, as well as "new forms of knowledge, institutional structure, and problem solving" that prompt dialogue across disciplines (pp. 4-6).

Real-world problems cannot be force-fitted to suit disciplinary boundaries, and this is an additional motivator for interdisciplinary collaboration (Jeffrey, 2003, p. 539). Notwithstanding disciplinary fragmentation certain elements still bind the academic community together (Becher and Trowler, 2001, 17). For example, interdisciplinary collaborators believe "new knowledge is new power, expanded knowledge is expanded power, and fragmented knowledge is fragmented power" (Clark, 1987, p. 273). Thus, importantly, researchers share their work to satisfy needs when collaborating. Whatever the approach the social context still subsumes the science and the collaboration: peer review, epistemologies and ontology, science policy, disciplinary and academy standards (Sonnenwald, 2007).

Methods

Our collaboration was not experimentally examined or quantitatively measured. We did collect samples and analyze them in the laboratory as part of our work, but the qualitative nature of our work and experience with international interdisciplinarity and collaboration ultimately proved our guiding light. During our time together we largely focused on the social dimensions of collaboration. Important to us were the processes stemming from our work, and the sociality of our experience manifested meaning throughout. So, we present here some of the in-country groundwork we performed as part of a holistic and emergent methodological approach.

From late April to May of 2017 we made a field visit to Segovia-Remedios, Antioquia, to visit mines, mining sites, and ore processing centers (i.e., Entable El Trébol, Mina El Pujido, Mina El Cogote, Mina El Playón, Entable Planta La Palma). We interviewed our accompanying undergraduates (mining and metallurgy engineering students) via online questionnaire. We then visited with the mayor of Andes, Antioquia, to discuss a clean-up and mitigation project entitled *Implementación de tecnologías sostenibles para la recuperación de pasivos ambientales y la eliminación del uso del mercurio en la minería de oro artesanal en el municipio de Andes–Antioquia*. Finally, we prepared a case study proposal for a later comparison of select areas of Colombia with select areas of Peru.

In June of 2017 we collected samples of various soils and sands in the mountainous region of Andes, hiking miles a day at various altitudes, braving torrential rains, lightning storms, and the crossing of treacherous rivers. We collected and reviewed our engineering student interview data from April to May, coding for themes and experimenting with data visualizations that we shared with other professional engineers at our laboratory. We regularly brainstormed about the diverse consequences of ASGM through hallway conversations, conversations in the laboratory, social time outside work, and in planned meetings. Another proposal was prepared at this time for the Diversity and Inclusion in Science Initiative Graduate Research Conference at Arizona State University, which would take place the following year (2018). Also, a team member gave an interview to the highly esteemed in-country publication *Semana*.

In July of 2017 we further convened to dialogue about the consequences of ASGM. Subsequently, we worked on a international interdisciplinary collaborative research design based on our experience: (1) start with a socio-technical problem; (2) work osmotically in an interdisciplinary collaboration, both together and apart; 3) then, inform stakeholders and decision-makers of findings, ideas, processes, questions, and so on. We also initiated Colombia-Peru case study, and a team member traveled to and from Peru to perform it. The same member drafted an article eventually published as *Artisanal and small-scale gold mining in Colombia: Noise, geographic constructions of embodied civic identities, and the unanticipated consequences of modernising socio-technical activities*. Lastly, we presented on our collaboration to the members of our in-country host institute, CIMEX, including a range of engineers and technologists.

In sum our team was mainly collocated in Colombia and situated at the National Unviersity in Medellín. There, we collectively discussed the scope of our work. We ideated feasible projects, some of which we pursued. Given these projects we agreed to write about select parts of research and results in a paper such as this one. What follow are thus details of two select fruits of our work. The first is a workshop developed by the Colombian engineers on our team in partnership with additional collaborators outside our team nucleus. The National University of Colombia hosted this workshop. The second is a presentation developed by the American researcher; it was hosted by Arizona State University.

Results

Workshop

Through the program Partnerships in International Research and Education (PIRE) the Colorado School of Mines received a grant from the United States National Science Foundation (NSF) for the project entitled "Sustainable Communities and Gold Supply

Chains: Integrating responsible engineering and local knowledge to the design, implementation and evaluation of solutions for artisanal mining in Latin America.” Within the framework of these projects the School of Mines of Universidad Nacional de Colombia and Colorado School of Mines invited the academic community, local, regional and national institutions, communities leaders, associations, and mining companies to participate in a workshop in Medellin, Colombia (December 6-7, 2017). The title of the workshop was *Social dimension of the successful development of mining projects – A focus on Artisanal and Small-scale Mining (ASM).*

In part this workshop resulted from the work of the lead Colombian engineer on our small team, and it was somewhat orthogonal to our team’s primary work and purpose. Our team participated in the workshop, which marked the desire of the School of Mines of the National University of Colombia to contribute to discussions and initiatives involving ASGM. Specifically, our team’s connection to the workshop included our direct participation in a project (“Implementación de tecnologías sostenibles para la recuperación de pasivos ambientales y la eliminación del uso del mercurio en la minería de oro artesanal en el municipio de Andes–Antioquia.”) presented under the framework of the National Call for Solidarity Extension – 2016 National University (NU) of Colombia: Social Innovation for Peace (i.e., *the Implementation of sustainable technologies for the recovery of environmental liabilities and the elimination of mercury use in mining artisanal gold in the municipality of Andes – Antioquia*).

Overall, the workshop acknowledged that in Colombia, Peru, and other Latin American countries different scales of mining activity normally develop in areas with high social, economic, and environmental complexity. ASGM is a mining sector that continues to grow and pose opportunities and challenges for governments, industries, communities, and academics. While the analysis of economic and environmental aspects of ASGM has well-developed technical, scientific, and normative tools the social dimensions can generate great uncertainty. The models and instruments for the study and management of ASGM activities and its social components must address – at the earliest stage of development – the diverse expectations, groups, and complicated interactions between the various actors involved in these systems.

Based on the dynamics and socio-economic diversity of the mining-sustainable development relationship an approach has been proposed that addresses the contributions that ASGM can make to benefit territories and rural communities. However, current in-country situations present major challenges that pressurize already complex scenarios. Thus, efforts should be directed at building trust to strengthen a multi-sector dialogue where various actors converge, including institutions (local, regional and national), communities, associations, companies and academia, particularly with the purpose of finding inclusive solutions in which all stakeholder needs are identified and addressed. Understanding the conditions that may contribute to the development of more effective relationships and the achievement of results in accordance with the contexts in which mining development takes place is an issue of vital importance.

Some of the objectives of the workshop were: (1) to generate a multidisciplinary and interdisciplinary space for reflection among the different actors involved in the ASM activities, to allow for the discovery of challenges, threats, and opportunities associated with the development of these activities in Colombia and Peru; (2) to socialize the activities contemplated in the UN Solidarity Extension project, and the NSF PIRE project and the results obtained in them; (3) to propose actions that foster contributions and help develop more effective relationships, as well as the achievement of results in accordance with the contexts in which ASGM development takes place.

Workshop guests included participants from various academic institutions: Universidad Nacional de Colombia – Thinking Center Responsibility and Sustainability of the Mining Industry; Universidad Nacional de Colombia – Institute of Minerals CIMEX; Universidad Minuto de Dios; Pontificia Universidad Católica de Perú; Universidad de Ingeniería y Tecnología, Lima, Perú; Universidad de Oviedo, Spain; Colorado School of Mines; University of British Columbia; West Virginia University; Arizona State University. Workshop guests also included participants the institutional sector: National Mining Agency (Agencia Nacional de Minería); Grupo Proyectos de Interés Nacional (PIN); Secretaria de Minas de Antioquia. Additionally, there were guests from the mining sector: Mining Communities – Asomisura; National society for small scale mining (SONAMIPE), Peru; and mining companies (e.g., Continental Gold, Gran Colombia Gold, Mineros S.A., Alliance for Responsible Mining).

Expected outcomes included an open and respectful discussion space among the different stakeholders concerning the social, economic, political, and environmental conflicts associated with mining developments and preparation of conclusions for each of the proposed working groups assembled in the workshop. There was a discussion workshop with worktables, each lasting half a day. To advance each session collaborative methodologies, such as *Design Thinking*, or *World Café*, were used in conjunction with the presence of a moderator who facilitated the discussion. Some of the proposed topics included perspectives of communities against mining development (small-, medium- and large-scale); statal obligations to communities (policy directives); triggers and threats in the relationship between mining companies and communities; socio-technical interventions among the ASM sector aimed at promoting more sustainable ASM livelihoods; particular challenges to working with ASM communities and how to mitigate those challenges; conflicts within the ASM supply chain.

Tune-in!

This presentation is another example of the fruits of our work, an outgrowth of our collaboration. It was presented at the Diversity and Inclusion Science Initiative (DISI) Graduate Research Conference at Arizona State University (2018). An abstract[1] was

[1] Today, listeners experience music as being apart, or distinct, from other dimensions of civic life. But the two cohered for the Ancient Greeks; cleaving music from its political import would have made little cultural sense. In fact, the political and ethical values of musical attunement enabled Plato to design his ideal metropolis, and musical harmony breathed life into Aristotle's ethical ideal. Indeed, millennia ago, music informed intellectual and spiritual formation; it marked the ethos of both individuals

submitted by a team member to conference reviewers. This musical performance was interactive. Participants manipulated audible media simply by moving their bodies about a given space, effectively making music and noise. The corporeal experience spoke to the intersection of music and qualitative research interests in many areas (e.g., science and technology, architecture, geography, communication, anthropology, digital design, and social technologies). Moreover, the music and sound, which participants manipulated with their bodies, consisted of digital photos gathered from Colombian research partners with disciplinary backgrounds in art, engineering, development, mineral resources, the environment, and more. Their photos were digitally reproduced as sound, which participants could engage with physically.

Participant learning objectives included: evaluating the merits of interactive artistic performances as conduits or catalysts for greater instances of collaborative, interdisciplinary research; formulating ideas for possibly even more interactive, artistic research performances as a means of advancing and publicizing scientific work both at home and abroad; discussing interactive art as inspired and generated by collaborative and interdisciplinary research at home and abroad; describing the experience of making music by moving about a given space and manipulating media.

The facilitation plan included the following. Each session lasted as long as participants cared to engage in creating music and sounds within the designated interactive space (i.e., a few moments to several minutes). Roughly eight square feet of space were necessary, and electrical outlets were required to power the interactive experience. A deejay and sound engineer helped in actualizing the interactive performance and in setting up the audio equipment. Handouts explaining the artistic inspiration of the performance, as well as the

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and their societies. Presently, geographers endeavor to show that the spaces in which people work, live, and play are crucial to comprehending politics and power. Music, and the noise of modernizing activities, moreover, still fill these spaces globally; they are replete with media, which communications theorist Marshall McLuhan qualifies as "any extension of ourselves" that results from "the new scale that is introduced into our affairs by each [medium], or by any new technology." Technologist and rock music critic Langdon Winner further observes that "the greatest latitude of choice exists the very first time a particular instrument, system, or technique is introduced." In hindsight, this combination makes for manifold "unanticipated consequences" that are perhaps difficult to perceive because of a predominant fixation on more obvious ones. Nevertheless, they reverberate throughout global spaces which are vital to power and politics, geographies where people yet undergo spiritual and intellectual formations. For example, whether deep within the mines, gold processing sites, or boisterous towns and cities of mining stakeholders, perpetual noise exposure is a remarkable aspect of everyday life for millions of artisanal and small-scale mining stakeholders. Several municipalities in Antioquia, Colombia, comprise a milieu of my own phenomenological research on artisanal and small-scale mining; they exemplify the coincidence of music, noise, and mining activities. The summative sociotechnical activities that propagate sound in these municipalities further evince that stakeholders constantly galvanize their space with music and noise. … interactive musical representation of gold mining municipalities in Colombia is furthermore a creative approach to sharing the sociotechnical effects which unfold in stakeholder contexts, or research sites. Moreover, it renders audible the experience of unanticipated consequences of modernizing activities (e.g., multisource noise pollution), and the musical aspect induces a physical aspect common to research experiences. By having their bodily senses affected by sound, participants encounter physical phenomena indicative of various co-producing sociotechnical activities. This will hopefully foment greater curiosity and possibly inspire new, artistic research. Finally, this interactive musical performance gives participants the chance to manipulate music and sound simply by engaging with a given space, a thoroughly phenomenological experience. Music and noise are derived from visual media captured in mercury-contaminated gold mining municipalities in Colombia, where researchers often function as photographers. Their images are converted into a wave table and played through a synthesizer. Then, the physical interaction participants have with audio re-presents the experience of engaging in research with underrepresented stakeholders around the world, namely those who are oppressed by the unanticipated consequences of sociotechnical systems, innovation, and modernizing activities and rendered invisible by the obvious ones (Pimentel, 2017).

undergirding intellectual, research, interdisciplinary, and collaborative international dimensions of the performance, were made available to conference participants and others.

Discussion

In conjunction with the literature review above our discussion here is a springboard for additional international interdisciplinarity to be further shared and studied. The design of our research was more emergent than planned. As our collective sense of what it meant to engage in international interdisciplinary research deepened, and as our work and projects changed, we responded fluidly. Rigid designs and approaches would have been insufficient. We could not rule out engaging in new opportunities and pursuits as they arose. Any approach we have taken in our analysis has been largely holistic. We recognize the mercury contamination crisis in Colombia stemming from ASGM is complex and dynamic. Causal relationships exist but among them are inextricable interdependencies. Our approach was therefore sensitive to context in the sharing of our work and experience, and now it is somewhat reflexive as a result. Experiences such as ours may coincide with social transformations already underway around the world. We are thus prompted to question the degree to which international, interdisciplinary collaboration is vital to social transformation, stability, and peace. And so, we have endeavored to present outgrowths and insights from our own experience to illuminate the nature of our collaborative undertaking. We recognize there is potentially more to our collaboration than we share here.

Each of our team members can attest that internationally situated research makes for gratifying work. As Hackett (2004) recalls Max Weber once saw the rewarding work of science as “a vocation to which few are called and those called become deeply dedicated.” Truly, for the individual researcher, such work offers the freedom and the chance to grow, as well as an authentic chance to produce new knowledge (p. 751). Doing this across borders international, interdisciplinary collaboration can do much to address complex problems despite the political borders made so indelible by nation-states. It was never lost on us (as members of an international, interdisciplinary research team) that mercury contamination daily affects the lives of hundreds of thousands of miners in Colombia, and that markets for gold are deeply international. We never viewed borders as trivial relative to our work. In addition to Antioquia our team observed that Peruvian gold miners commonly supplement their incomes with mining practices. We therefore performed a cursory case study between specific sites in Colombia and Peru, whereby we sought to better understand, for our own sake and that of myriad stakeholders, the similarities and differences between the two states, their publics, their imaginaries, and any corresponding relationships of gold mining practices that might have arisen in conjunction with the recent global uptick in gold prices.

In light of our ability to move across international political borders, to arrange a confluence among institutional energies, to bring to bear multiple talents and capabilities on the problem confronted, and to establish enduring professional research relationships we believe our collaboration was successful. Shrum et al. (2001) add that contributors view sizable, international collaborations to be “more successful in the eyes of their colleagues” (pp. 716-717). If, in the eyes of our colleagues, the international dimension of our collaboration enhanced any perceptions of success relative to our work, then we might further ask, for the same reason, if we ourselves perceive our own work to have been successful. Throughout our collaboration we sought to develop and engage in innovative and meaningful work and projects. We desired these to be at once practicable and collaborative. To some degree we differed in our hopes, objectives and the personal commitments that prompted our collaboration. This did not diminish our compatibility, however. Instead, our team's diversity was enriching. We endeavored to surmount the shortcomings that arose. Consistently, the engineers shared their research responsibilities, laboratory-based instruction, and personal insights on the social and scientific aims of engineering interventions; local and national politics; policy; and the human and social dimensions of ASGM, including culture and identity.

The knowledge produced by international interdisciplinary collaboration functions as a product of all the border-crossing dynamics folded into its making. We understand political borders as being inherent to international competition for political autonomy and natural resources, as well as that they have a moral dimension. Borders matter, as do location and proximity. Olson and Olson (2000) thus believe that collocated work requires that contributors inhabit the same space, "either temporarily because they have travelled to a common location or permanently because they are at a common site." They define "same location" as being within walking distance, work-wise. Also, they assume collaborators are able to access "common spaces for group interactions (meeting rooms, lounges) and have mutual access to significant shared artifacts..." (p. 142). A shared location offers contributors the chance to perform collocated, mutual work, which further inspires and catalyzes collaboration, which was the case for us. Every day at the National University of Colombia our team shared laboratory and office space, even cohabitating from time-to-time on field visits or during sample collection excursions. We were therefore able to share thoroughly and to bond, enhancing our capacity for teamwork.

Collaboration participants elect to participate for various reasons. Personal significance is one that manifests in a number of ways. For example, collaborative approach to research portends exciting experiences and great meaningfulness for individual contributors. Collaborators who find themselves in scientific situations similar to ours may collaborate in the hopes of honing their skills, growing professionally, publishing, and having new learning experiences. For both graduate student members of our team (the American researcher and one engineer), such was the case. By working with a third team member, a senior faculty member and researcher at the School of Mines at the National University of Colombia both graduate-level team members hoped to develop skills, gain professional experience, take up new knowledge, and to publish (Hackett, 2005). Atkinson (1998) affirms that science involves competition, namely in publishing. Yet, our work involved efforts to surmount competition, even as we endeavored to produce knowledge and publish. But there is more to collaboration than publication, research experience, and professional growth: our American researcher experienced the death of a friend and neighbor in a mining-related accident in Peru; for both Colombian engineers the problem of mercury contamination is squarely in their backyard.

In addition to personal significance and meaningfulness collaboration happens because of the various commitments of individual contributors. Commonly, there are intellectual commitments that coincide with disciplinary empiricism and theory. Specific ontologies and epistemologies necessarily factor into empirical work. Even so, the engineering members of our team were highly amenable to new approaches to problem-solving that were social as much as technical in philosophy and approach. When a seemingly simple or elegant technological intervention did not suffice other angles and approaches and intellectual considerations were seriously entertained and sometimes brought to bear. Moreover, the dimension of *the personal* was apparent at various stages of collaboration, and some have argued that it takes "as much personal commitment to test an idea as … to discover it" (Mitroff, 1974, 586). We might contend that if our experience suggests anything in connection to the personal dimension of research commitments, it may be that some general aspects of collaboration align with personal motivating factors and existing personal projects or commitments. Ultimately, we focused on collaborating successfully to build working partnerships that might endure in light of longer-term and possible future projects.

We know that international, interdisciplinary collaboration is difficult without funding. Such resources can be scarce. Atkinson states, "Funding bodies wield considerable power, and often pressure is placed on researchers to focus on areas that have a commercial significance. … Research grants often depend on the results of previous research, and thus, financial as well as personal and social rewards are at stake…" (pp. 268-269). Partnerships between governments, across institutions, and universities in different countries can each help to mitigate issues in funding. Such contributions allow research groups or science teams to do research beyond borders and across hemispheres. Teams like ours may additionally rely on nonfinancial elements like attitudinal elasticity to ensure viability. Hackett (2004) analogizes that collaborative research parallels "that of sailors who continually rebuild their ships amid the turbulence and resource scarcity of the high seas…" In time adaptability and flexibility are key: even small decisions can greatly affect a research team and shape of its entire collaborative trajectory (p. 747).

In additional to elasticity something else imparts a tensile strength to a collaborative team and its contributors. Collaborations depend on consent, consensus, and diversity, all of which differ markedly from subjugation or forced work. For example, our team was very democratic and transparent in sharing concerns and communicating anticipations and misgivings relative to work and individual aspirations. Yet, a commitment to collegiality and democracy does not preclude conflict. Shrum et al. (2001) state, "The organizational complexity of collaboration requires trust, but also offers the potential for conflict. Conflict, of course, may be both disruptive and stimulating to the social fabric." Conflict circulates where there is hierarchy, and research projects may adopt hierarchical dimensions, or at least appear hierarchical from outside. From an insider perspective, though, there may actually be a great degree of horizontality (p. 684). This partly makes possible sociality, and sociality certainly factored into our collaboration. Freely, and with regularity, the two junior contributors to our collaboration would defer to the senior faculty member leading our group, our workload, and our research objectives.

We believe the elective nature of collaboration is a key to collaborative viability: "The voluntary commitment to enter the collaboration often means that at the highest levels, there are relatively egalitarian relationships" (Chompalov, 2002, 765-766). There existed a social unanimity among contributors in our research group notwithstanding elements of leadership, competition, cooperation, and control. Hackett (2005) insists such are "not pathologies, but the inherent and enduring tensions that confront every research group, and the group's direction and fate are shaped by the choices it makes" (p. 788). Ultimately, then, in the course of collaboration, control critically rests with the group, and the group begets sociality.

Collaboration itself, squarely an age-old component of science, invites contributors to consider always more. The viability of collaborative groups depends on more than one-off individual inputs prompted by personal relevance and a forecast of individual hopes. In our case we ended up ideating a much more socially nuanced response to the problem of mercury-use contamination in ASGM in Colombia, the collection of samples, the inspection of technological interventions *in situ*, and the interaction with workers, which greatly informed innovations in our thinking and our approach to comprehending the phenomenon much more robustly. Though researchers collaborate for many reasons we recognize teams like ours likely face a range of factors, some of which we broach throughout this paper.

Conclusion

Collaborative scientific work regularly occurs around the world. It spans continents, cultures, institutions, disciplines, languages, and more. Here, our contribution has been to document and report on our teamwork and on select outcomes. Specifically, we have shared our international, interdisciplinary response to ASGM and mercury-use reduction in Colombia. Though we presented select projects and outcomes to demonstrate our share in international interdisciplinary collaboration we also touch on relevant points in the literature. Where suitable we reflect on the place and value of our experience relative to the literature. The simple act of sharing our experience might inform new thinking, new publications, spark new dialogues with and among stakeholders, impact future generations of mining engineers and other researchers or research teams, or contribute in some way to enduring peace. In adopting an international interdisciplinary approach our hope is furthermore to aid or inspire those who like us work to respond to complex problems, such as mercury contamination in ASGM, by bringing their expertise and capabilities to bear.

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