Can Community Development Projects in Engineering Education Be Both Responsible and Sustainable?: Theory, Education, and Praxis

Dr. Juan C. Lucena, Colorado School of Mines

Juan Lucena is Professor and Director of Humanitarian Engineering at the Colorado School of Mines (CSM). Juan obtained a Ph.D. in Science and Technology Studies (STS) from Virginia Tech and a MS in STS and BS in Mechanical and Aeronautical Engineering from Rensselaer Polytechnic Institute (RPI). His books include Defending the Nation: U.S. Policymaking to Create Scientists and Engineers from Sputnik to the 'War Against Terrorism' (University Press of America, 2005), Engineering and Sustainable Community Development (Morgan &Claypool, 2010), Engineering Education for Social Justice: Critical Explorations and Opportunities (Springer, 2013), and Engineering Justice (with Jon Leydens, Wiley, 2018)

Can Community Development Projects in Engineering Education Be Both Responsible and Sustainable?: Theory, Education, and Praxis

This paper outlines the relationships between students, socio-technical systems, resilient communities, and community development projects in engineering education, focusing on how students can become socially responsible and projects deliver sustainable community development. Using artisanal and small-scale gold mining (ASGM) as an area of application for engineering students involved in community development, the paper first describes the characteristics that communities should exhibit and what they should expect of engineers in order to achieve community resiliency. Second, it outlines criteria that engineering students should adopt as behavioral guidelines in order to act in a socially responsible way. Third, it describes criteria that engineering projects should have in order to contribute to sustainable community development. Fourth, it describes the integration of these two set of criteria in the engineering curriculum in order to develop conceptual understanding and practical skills that engineering students can apply when engaging communities. Finally, it concludes with lessons learned from this criteria development and curricular integration for engineering educators committed to educating students to become socially responsible engineers and making their projects both socially just and sustainable for communities.

1. Introduction

In engineering education, there has been a proliferation of projects aimed at community development, most of these motivated by strong personal desires to help solving big and complex problems like poverty, climate change, lack of drinkable water, etc. and also by institutional needs to enhance students experiences and professional development, exposure to international education, and, in some cases, to contribute to program accreditation .

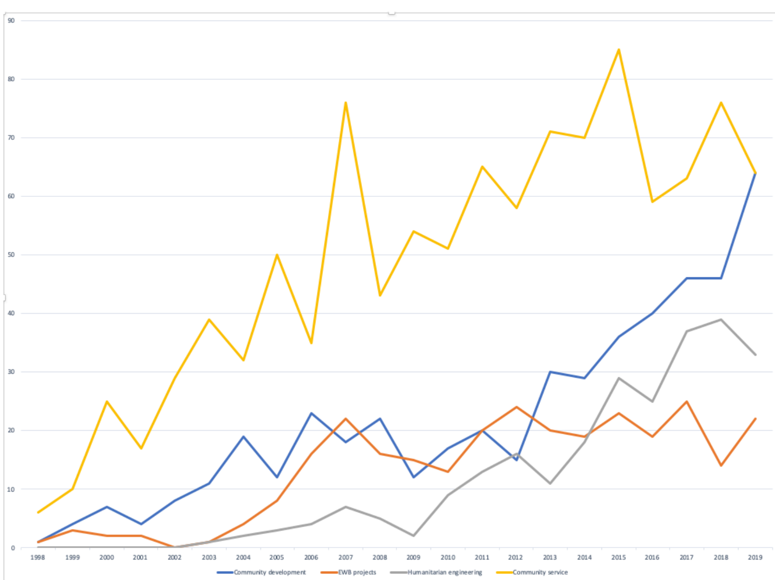

Figure 1. Growth of number of papers presented and published in ASEE conferences between 1998-2018 on projects related to community development, EWB, humanitarian engineering and community service (Source: peer.asee.org database)

But what if these problems are so complex that they cannot be solved by engineering projects alone, and certainly not by engineers in training operating in highly constrained educational environments (e.g., 50-75 min classes, 14-week semesters, design classes away from communities, etc.) and under limited resources of time, money and expertise? Where and how can/should engineering educators focus their attention and resources to develop, organize, integrate, and support these projects so they can be more effective and sustainable into the future? What kinds of criteria should guide how we teach students to assess the communities they want to work with? And once they identify potential communities, what criteria should guide their behavior and the projects to serve those communities? Can these criteria be taught in the classroom and/or implemented in project spaces in our engineering programs? This paper aims at answering these questions and providing a roadmap to organize and deliver community development projects in a responsible and sustainable way.

2. Motivation of engineering for community development (ECD) projects

Marked by the emergence of "Engineering to Help" programs (EWB, Humanitarian Engineering, community development, community service, etc. ca. 2000 as shown in Fig 1), ECD projects have been motivated by faculty and students desire to help, personal and career goals, desires to study and work abroad, and desires to solve problems and to gain hands on experience on impactful work [1][2]. Since then, some scholars have called our attention to how the focus of well-intentioned ECD projects on technological fixes and deliverables tend to leave out critical reflections of engineers' motivations to be in these projects, and of the processes required to build trust and determine communities' priorities and desires [3][4]. Unfortunately, these calls to critical reflection in the ECD space are often overshadowed by the continued emergence of milestones and challenges (e.g., UN Sustainable Development Goals, NAE Grand Challenges), ever changing institutional priorities (e.g., the craze over innovation and entrepreneurship in engineering education), many of which are uncritically adopted as givens even when these hide significant power dimensions that put the communities we are trying to serve at a disadvantage [5][6].

At the same time, students involved in ECD projects often lack the required sophistication to understand the complex structural forces behind large problems like poverty, climate change, etc. and naively participate in ECD projects without normative guidelines for how to identify communities, how to behave when engaging communities, or how to develop projects that will be conducive to socially just and sustainable community development. So what are we and our students to do? Instead of pretending that ECD projects are going to make a dent in solving the world's complex problems like poverty or climate change, just because they might be inspired by SDG's or some form of engineering grand challenges, we should develop the humility to accept that ECD projects won't solve these problems and that, the best we can hope for is that, they might make a positive difference in communities' ability to deal with poverty or climate change. How can we teach our students this humility and the ability to identify communities where they can make a positive difference?

3. Theory 1: Resilient Communities

Most of the structural problems affecting poor communities (homelessness, violence, climate change, hunger, etc.) cannot be solved by engineering alone. While engineers need to understand the structural conditions in which they operate (see SRE criterion 1 below), we need to be careful when promising technocentric solutions to large complex problems since 60 years of international development have shown us that most of these do not work [7]. Instead, when facing these complex problems, engineers can be better positioned to contribute to the resiliency of communities to adapt to the consequences of large complex problem like poverty or climate change. Resiliency can be understood as the human capacity to face and overcome adversity (e.g., the consequences of poverty), and, hopefully, come out stronger and transformed even while staying in poverty [8][9]. While the concepts of "resilience" or "resiliency" are now in vogue in engineering academic circles, these are seldom understood, especially in relationship to ECD projects. If we want to enhance resiliency in communities through our engineering projects, we have to be careful that our efforts do not become exclusively technocentric. A preliminary review of the literature in resiliency in ECD projects shows that most place resiliency as either a characteristic of the built environment (infrastructure) or as the attitude that engineering students must develop to succeed in a demanding curriculum [10][11]. But how about *resiliency* as a latent characteristic of communities that can be both enhanced by the way engineers behave when working with communities and by the ECD projects they define with and deploy in those communities?

First, we need to recognize three essential categories of elements that need to be present in a community in order to begin building resiliency: Extrinsic, Intrinsic, and Relational [12][13][14]. Using examples from a course titled *Responsible Engineers, Socio-technical Systems, Resilient Communities,* funded by an NSF project aimed at teaching engineering students how to work with artisanal and small-scale gold mining (ASGM) communities in Colombia and Peru, I will outline these categories and briefly explain how to prepare students to identify these categories in order to assess whether or not a community has the necessary conditions for resiliency (see section 6 below for full description of the course).

Extrinsic. If communities have not experienced *external adversity*, they do not have anything to be resilient to. Hence in order to start building resiliency, communities need to have experienced external adversities such as traumas, disasters, and threats that come from large systemic of structural problems like poverty, climate change or violence from organized crime. For ASGM communities, these often include the threats from criminal activity related to ASGM (e.g., financing of violent groups through gold mining), neglect of state organizations, corruption, extorsion, systemic discrimination (of women miners, for example), chemical toxicity such as mercury poisoning, the presence of multinational corporations that compete for mineral resources, geological hazards, among many others [15][16][17]. Students in my class learned about these external adversities as follows. First, they read and understood the linkages between poverty and ASGM [18] and how the conditions of poverty and illegality in ASGM are often perpetuated by systemic problems in the formalization of the ASGM sector [16]. Second, following community connections that faculty developed for more than a year, students connected with ASGM community members (via WhatsUp or Skype) to see how they experienced these adversities. This understanding of and connecting with ASGM communities proved very effective during the subsequent summer field trip (see Section 7 below).

Intrinsic. For resiliency to occur, there has to be a history of *positive adaptations* intrinsic to a community that has tried to overcome adversity. In ASGM communities, these have included mercury detoxification programs [19], territorial local planning that keeps ASGM away from watersheds [20], the desire of groups that have been discriminated to organize to gain voice and power [21], etc. For these type of positive adaptations to occur, communities must exhibit the following characteristics: *Collective self-esteem* (love who you are as a community); *Cultural identity* (know who you are as a community); *Social humor* (be able to laugh at who you are); and *State honesty* (transparency between local/state government and communities) [14]. Students in my class learned about these positive adaptations by researching the above characteristics through local newspapers and radio stations where collective self-esteem and humor can be identified, and local-government websites that exhibit different degrees of state honesty. For our particular ASGM community in Colombia, they learned that there are high levels of collective self-esteem and humor, significant transparency of the local government but that state and national government processes related to ASGM are obscure at best, hence presenting a significant obstacle for resiliency of communities. To overcome the hurdles of state bureaucracy and lack of transparency, many ASGM communities have to resort to informality and illegality [16] and students have to define problems and propose solutions within this reality.

Relational. This element refers to *social trust* as the main element that needs to be present between a community and outside experts (like engineers) to build resiliency. For engineers working with ASGM communities, for example, in order to gain social trust they need to show a) *competence*, not only in an engineering domain but also in building and managing the social relations that make projects possible; b) *caring*, not only about the technologies but also about the people impact them by them; c) *predictability*, showing that you are going accompany and be accountable to ECD projects from start to finish and thereafter; and d) *commitment to diversity* of perspectives and interpretations (e.g., various representations of the problem and possible solutions) [12]. Students in my class learned about these elements through group exercises where they were challenged to develop interactive activities with communities where students could present their competence, caring, willingness to accompany communities for the duration of the project, and commitment to include many voices during the different stages of a project. These activities were piloted in class and will be validated in direct contact with communities during summer field work.

While engineers have little, if any, control on the intrinsic and extrinsic elements of resiliency, they need to able to identify them and consider them as contextual constraints in their problem definition and designs. Certainly, engineering students can have significant influence over the relational dimension by cultivating social trust by exhibiting competence, care, predictability, and commitment to diversity. But in doing so, what should the guiding principles of students' behavior with communities be?

4. Theory 2: How should engineers behave with communities?

In a different writing, we have shown how engineering ethics benefit the relationships that engineers have with corporate employers while not serving as appropriate guides in their relationship with communities. [22] To overcome the limitations of engineering ethics (the codes and the forms in which they are taught), we developed a set of criteria for socially responsible engineering (SRE), which I highlight here with examples of how students began developing these in their role as engineers who will be working with ASGM communities:

Criterion 1. Understanding structural conditions and power differentials among specific stakeholders of an engineering project. In our course, students researched and understood how mining law and codes benefit large scale mining companies more than ASGM miners, or how among ASGM miners, men have more power and benefit more from mining than women miners [23]. Students were able to validate these research findings through in-class teleconference exchanges with engineers from large mining companies and women miners.

Criterion 2. Contextually listening to all stakeholders, especially those who are marginalized, to grasp their needs, desires and fears surrounding a specific project. In our course, students listened how to the histories of miners, paying particular attention to how they got there, what their struggles are, and to the stories of disempowered groups like women and indigenous populations who have been unequally affected by mining [24][25]. To get this knowledge, our students interacted in person with an anthropologist who has studied and written about ASGM in Colombia [26] and a lawyer-activist who fights for the rights of ASGM communities, and virtually with a number of other actors invested in the well-being of disempowered groups in ASGM [27]

Criterion 3. Collaboratively identifying opportunities and limitations of creating shared social, environmental and economic value for all stakeholders, especially those who are marginalized. We are teaching our student cohorts how to do this by showing them how others have organized and delivered workshops [27] to bring different stakeholders together to identify opportunities that contribute to social (e.g., creating associative corporations), environmental (e.g., reduce use of mercury), and economic (e.g., increase income diversity) value. Then students can emulate these collaborative practices in their own ASGM-related projects [21].

Criterion 4. Adapting engineering decision-making to promote those shared values, acknowledging situations in which this is not possible and when engineering projects should not move forward. In our course, we taught students how if one dimension of ASGM stops being profitable, safe and/or environmentally sound (e.g., dispersed gold processing plants that might be polluting different watersheds), engineers can engage communities in proposing and jointly create alternatives (e.g., a centralized processing plant that benefits from economies of scale for all and environmental supervision). Unfortunately, in the ASGM areas where we work, these alternatives have been developed solely by engineers without the input from communities. Our students are learning about the perils of not engaging communities.

Criterion 5. Collaboratively assessing activities and outcomes with those stakeholders. In ASGM contexts, this could be done by teaching students how, for example, if the process to decide, design and build a centralized processing plant is the result of a joint effort between engineers, ASGM communities, and local government, then a collaborative process for continuous feedback and improvement should be put in place to assess the costs and benefits of the plant. In our course, we played out a hypothetical scenario where I invited students to imagine that the centralized processing plant described above had been designed with community input and then “describe how you will adapt engineering decision-making to promote those shared values, acknowledging situations in which this is not possible to do so and engineering projects should not move forward. Please be specific about engineering decision-making. Remember that engineers build systems, processes, infrastructures, technologies, etc. that legislate, even after elected officials end their terms."

How do these SRE criteria map to social trust? Without doing an exhaustive analysis of how each criterion contributes significantly to building social trust (as this will be done in other publications), one can see that, for example, contextually listening to all stakeholders (criterion 2) contributes to *competence*, as engineers would understand how a proposed project would affect stakeholders differently (and vice versa); *caring*, as stakeholders would see how engineers care about their histories, struggles and hopes in relationship with the proposed project; *predictability*, as engineers would come to understand the importance of "being there" or "coming back" for different stakeholders; and *commitment to diversity*, as engineers would understand how the jointly defined problem and proposed solutions would mean different things, have different interpretations, and elicit different predictions to different stakeholders. (see table 1).

Elements of social trust **SRE CRITERIA**	**Competence**	**Caring**	**Predictability**	**Commitment to diversity**
1. Understanding structural conditions and power differentials	✓	✓		✓
2. Contextually listening to all stakeholders	✓	✓	✓	✓
3. Collab. identifying opportunities & limitations of creating shared SEE value	✓	✓	✓	✓
4. Adapting engineering decision-making to promote those shared values	✓	✓	✓	
5. Collaboratively assessing activities and outcomes with those stakeholders	✓	✓	✓	✓

Table 1. How each SRE criterion contributes to different elements of social trust. Note that the check marks can be replaced with actual numerical ratings based on survey data that students can gather by deploying questionnaires in ASGM communities. Our new cohort of engineering students is learning these survey techniques in a Community-Based Research course.

But even if we can develop *social trust* between resilient communities and socially responsible engineers there is no guarantee that jointly defined projects will actually contribute to community development in a sustainable and socially just way. What kind of criteria should guide engineering projects aimed at sustainable community development?

5. Theory 3: Guiding Criteria for Engineering Projects with Communities

According to rural sociologists Bridger and Luloff [28], sustainable development has not been achieved since its adoption in the early 1990s because its well-intentioned goals and practices have been appropriated by the technocrats of international development who live and work far removed from the daily struggles of most people on the planet (for a full critique of sustainable development discourse, see [28]. For a critique of the planning mentality behind sustainable development, see [29]). Hence they challenged us to conceptualize, develop and practice sustainable development in the localities most affected by macro-scale phenomena as climate change and social inequality: communities. They write:

> [b]y shifting the focus on sustainability to the local level, changes are seen and felt in a much more immediate manner. Besides, discussions of a 'sustainable society' or a 'sustainable world' are meaningless to most people since they require levels of abstraction that are not relevant in daily life. The locality, by contrast, is the level of social organization where the consequences of environmental degradation are most keenly felt and where successful intervention is most noticeable…sustainable community development may ultimately be the most effective means of demonstrating the possibility that sustainability can be achieved on a broader scale, precisely because it places the concept of sustainability in a context within which it may be validated as a process. By moving to the local level, the odds of generating concrete examples of sustainable development are increased. As these successes become a tangible aspect of daily life, the concept of sustainability will acquire the widespread legitimacy and acceptance that has thus far proved elusive [28], p. 380.

Bridger and Luloff proposed five criteria for sustainable community development that I have further developed with my students, making them appropriate for and operational in engineering projects, which we now call Engineering for Sustainable Development Community (ESCD) criteria. While these criteria are by no means all encompassing, we have found that they are comprehensive and effective to get novice engineers to focus on dimensions that are truly important in the communities where we work. In our ASGM projects, our students are encouraged to define and develop projects that incorporate all of these ESCD criteria and identify conflicts among tem. The five ESCD criteria, with specific examples related to ASGM communities, are:

Local economic diversity (LED). This criterion includes: 1) the creation of new local products/markets, which for ASGM communities could include the making of bricks, adobe, and other construction materials from remediated mine tailings; 2) production based on local resources, processes, relationships such as buying the equipment to remediate the tailings and make the bricks in local businesses so revenues are reinvested in local economy; and 3) capacity building and diverse local job creation such as the formation of local masons, brick makers, etc. that can benefit from the new locally available materials [30].

Political self-reliance of communities. This criterion includes: 1) autonomy in decision making such as the kind enhanced by associative organizations where ASGM communities come to their own decisions and voice them in front of more powerful actors like government agencies and multi-national mining corporations; 2) reducing dependency from external expertise and knowledge as it happens when ASGM miners engage our students on a leveled playing field to co-define problems and solutions together. In our work in ASGM communities, we encourage our students to link their projects to associative corporations (e.g., like the association of artisanal miners) so these can vet, support, help manage, and ultimately decide how and if the project should continue into the future [27].

Reduction/reuse of energy & materials in locality. This criterion includes: 1) conceiving projects through the "cradle-to-cradle" approach [31]; 2) improve energy efficiency and curb energy consumption in the design of the project sub-systems; and 3) include energy and materials storage capability to use excess energy and materials later. In our ASGM projects, we challenge students to incorporate organizations committed to the elements of this criterion such as securing energy from renewable sources to minimize dependency from the grid and/or involve organizations of women miners ("chatarreras") who can profit from recycling waste material in mines and processing plants [32].

Enhance biodiversity and careful stewardship of natural resources in locality. This criterion includes ensuring that projects and their by-products 1) will not negatively impact biodiversity or natural resources such as forests and rivers; and 2) can actually enhance the quality of natural resources such as when mine tailings are cleaned from heavy metals, removed from the environment, and used as construction materials. In our ASGM projects, we invite students to learn about the importance of biodiversity and natural resources directly from community members by listening to local stories about the meaning of rivers, mountains, forests, etc.

Social justice in locality. For the community impacted by a project, this criterion includes: 1) increasing opportunities (jobs, health, education, etc.) and resources (clean water and air, construction materials, income, arable land, etc.); 2) decreasing risks and harms (e.g., reducing heavy metals in the environment or improving ergonomics of mining tools to prevent injuries); and 3) enhancing human capabilities such as bodily health, bodily integrity, affiliation, and so on [33]. (For an extensive analysis of how to incorporate this criterion throughout the engineering curriculum, see [34])

6. Education: Curricular Integration of SRE and ESCD Criteria in Engineering Classroom

The motivation to bring ASGM into engineering education started with a NSF-Partnerships in International Research and Education (PIRE) grant titled Responsible Mining, Resilient Communities (RMRC), an inter-institutional, interdisciplinary, multi-country project aimed at researching, co-designing, implementing and evaluating sustainable ASGM technologies and practices with ASGM miners and affected communities in Colombia and Peru. Using the SRE, Community Resiliency, and ESCD criteria as organizing frameworks, I developed a course titled *Responsible Engineers, Socio-technical Systems, Resilient Communities* and its description and learning objectives reads as follows

> Through the lens of artisanal and small-scale gold mining (ASGM) viewed as a socio-technical system, this course explores the relationship between *responsible* engineering and the development and maintenance of *resiliency* in communities that historically have been ignored or marginalized by engineers and the organizations that employ them. Through in-depth readings, class discussions and projects, students will 1) study and analyze different forms of responsibility in engineering and resiliency in complex communities like ASGM communities; 2) critically explore strengths and limitations of dominant methods in engineering problem solving, design, and research for working with these communities; 3) develop understandings of effective forms of responsible engineering to work with communities, especially through the integration of social science concepts and methods in order to understand ASGM as a socio-technical system; and 4) research, develop, evaluate and present projects on how responsible engineering can lead to resilient ASGM communities.

In Spring 2019, the course was taken by the undergraduate and graduate students selected to work in the PIRE-RMRC grant. As stated above, one of the main goals was to research, scope, define and develop engineering projects that can contribute to resiliency in ASGM communities. This goal was to be achieved, first, by developing students' understating of ASGM as a socio-technical system. To do this, we applied existing conceptual frameworks from Science and Technology Studies (STS), mostly developed in the US and Western Europe, to understand socio-technical systems [35][36] and came to the realization that these conceptual tools are very limited when we want to influence systems for purposes of equality, resiliency and social justice. We discovered that STS literature on socio-technical systems (the socio-technical analysis framework) developed in the Global South [37] was more appropriate to understand ASGM in Latin American countries and to conceptualize the relationships between responsible engineers, resilient communities, and sustainable projects with the goal of improving the well-being of specific ASGM communities and situations in gold mining in Colombia.

Alongside this conceptual exploration of ASGM, students interacted with ASGM miners, community members, engineers working in ASGM settings, via tele-conferencing technology (Skype and others), and texting (WhatsApp) in order to validate their learning of ASGM as a socio-technical system, and begin identifying relevant problems to ASGM communities but viewed from different stakeholder perspectives. Students were able to synthesize their conceptual exploration and stakeholder interactions in the final paper for the class were, after having selected an ASGM project area from their research of and interactions with ASGM communities, I invited them "to revisit, apply and connect two cornerstones of this course: The criteria for Socially Responsible Engineering (SRE) and the criteria for Engineering for Sustainable Community Development (ESCD) to your chosen project. SRE is about YOUR attitude, knowledge and skills as an engineer working WITH communities. ESCD is about PROJECTS that might have a better chance to improve the living and working conditions of communities." Students successfully completed this synthesis as reflected by the average grade for the course in this final paper (90%) (see appendix A for full paper assignment). This conceptual exploration, validation and preliminary problem identification served as preambles for full project identification during summer field work.

7. Praxis 1: Problem Identification with ASGM Communities

During the summer of 2019, we took the group of PIRE-RMRC students to ASGM communities in Colombia: 5 undergraduates and 3 graduate students from Mines, 5 undergraduates from USAFA, 1 graduate student from CU-Boulder and 1 from University of Texas-Arlington. Prior to traveling to the ASGM communities located in an Andean mountain region of Antioquia, Colombia's main gold mining region, students spent one week in Medellin (Antioquia's capital) learning about the history and political economy of gold mining, directly from local faculty and students, mining engineers, mine owners, and local officials. Two PIRE graduate students ran a mini-workshop where they challenged undergraduate groups from US and Colombian universities to conceptualize the supply chain of gold mining and then to compare their different understandings of the supply chain given their different national origins and institutional locations.

After this one-week introduction of the ASGM context in the capital city, faculty and students travelled to Andes, Antioquia, a coffee and gold mining municipality aiming to become Colombia's first county free of mercury from gold mining. During this week, US and Colombian students partnered to

- Interact with miners, engineers, communities, local officials;
- travel to mines deep in the mountains to get a sense of the hardships involved in getting to the mines sites;
- visit processing plants where they took water and soil samples and learned about processes by talking to workers and plant owners;
- attend community meetings with women mining leaders in order to identify problems of importance to local miners but viewed from different perspectives;
- debrief their experiences at the end of the day and begin creating a map of the region where they could locate actors, communities, mining sites, natural resources (watershed, forests, etc.), sites of economic activity, etc.; and
- contextualize their problem identification with respect to human activity and the natural environment.

8. Praxis 2: Generating Problem Solutions and Potential Designs in the Classroom

After ten days of problem identification, faculty and students returned to the US with projects defined in the following problem areas: mine air monitoring, mine tailings remediation, miners' safety and health, and child education in mining communities. These identified problems found curricular space inside two design courses in Humanitarian Engineering (HE) where PIRE and non-PIRE students together work on generating problem solutions, conceptual design and prototyping.

EDNS 401: Projects for People. This course was developed for the HE program after realizing that traditional senior design courses are historically, organizationally and conceptually developed with assumptions that the final design is for commercial purposes for a for-profit client and not necessarily to address social change in communities. As I have written elsewhere, engineering design education for industry, specially its assumptions, design constraints and purposes, presents significant problems for design for communities [4]. In this course, students learn to “work with innovative organizations dedicated to community development to solve major engineering challenges [and generate] engineering solutions to real problems affecting real people in areas central to their lives” [38].

A PIRE RMRC-project faculty member taught the class in the Fall semester following the summer field trip dedicated to problem definition with ASGM communities. Through more in-depth stakeholder engagement, particularly by encouraging students to regularly check their design assumptions with ASGM community members and students in Colombia, students in this class developed plausible solutions in the three problem areas as follows:

- **For mine air monitoring**, students developed a prototype of a low-cost air monitor that miners can attach to their helmets or shirts.
- **For mine tailings remediation**, students developed a conceptual design to use remediated tailings as raw material to make construction bricks.
- **For miner’s safety and health**, students identified a number of ergonomic backpack designs to minimize back injuries when carrying ore out of mine shafts

EDNS 491-92 Engineering for Community Development (ECD) Capstone Design Studio. To continue addressing the problems associated with design for industry mentioned above, we developed a design studio environment inside of our university’s Capstone Design course that allows us to bring in multiple ECD projects at the same time, requiring different time frames for their completion, and different skill sets required from students. The students in this design studio are supported by faculty with backgrounds in anthropology, chemistry, engineering, and science and technology studies. The two main faculty members in charge of the ECD studio are developing course content and activities to achieve the following student learning outcomes (mapped in relationship to ABET criteria):

1. develop a project plan (including problem definition, design, and project completion) that can be accomplished during the allotted time period (ABET 2);
2. define problem, undertake research, and apply appropriate engineering knowledge to solve a design challenge in partnership with a community (ABET 1, 7);
3. gather information and communicate with community members and other stakeholders about issues related to problem definition, engineering design, analysis, decision making, and solution professionally in writing using methods, including design documentation packages, synthesizing feedback and putting it into action (ABET 3);
4. gather information and communicate with community members and other stakeholders verbally using methods, including formal design review events, synthesizing feedback and putting it into action (ABET 3);
5. identify and analyze the ethical, environmental, societal, and/or economic impacts that your engineering interventions can have for community partners and other stakeholders, and incorporate these findings into problem definition, engineering design, analysis, decision making, and solution (ABET 4);
6. function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives (ABET 5), and;

7. evaluate your success as a designer by reflecting on your experience and proposing strategies for future self-improvement (ABET 7). (Cite Reddy and Handorean RM ASEE poster)

For the first semester (EDNS 491) of this two-semester Capstone sequence, the projects come directly from three sources of problem identification: a) in-depth problem identification with communities during summer field work; b) EDNS 401 Projects for People course; and c) new interactions and problem identification at a distance with local communities and in-country stakeholders (See Figure 2). During this first semester, students continue to further define the problems with community members and other stakeholders in order to have a well-defined problem and conceptual design by the end of the semester.

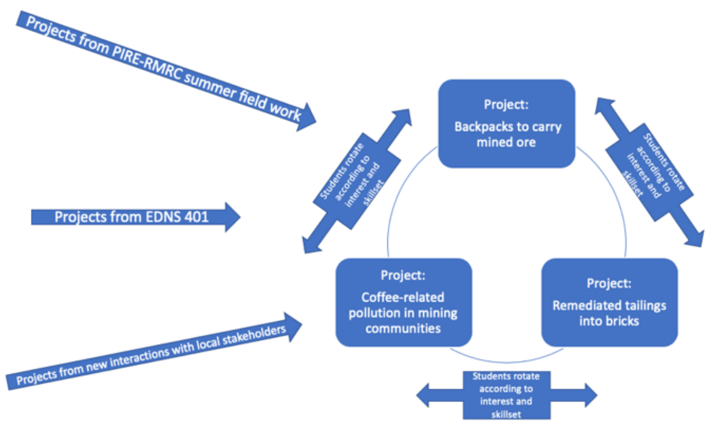

Figure 2. ECD Design Studio model

In the second semester (EDNS 492), students will continue working towards the achievement of the learning objectives above and develop design prototypes that the new cohort of PIRE-RMRC students will take to Colombia to be validated with ASGM community members (see below). This ECD design studio model also allows for projects to flow back and forth between students in US and ASGM communities abroad, ensures that their continuity, refinement, scaling (up or down) and the emerge of new ones have a stable curricular space.

9. Next steps

After creating this community-based and conceptually grounded environment for projects to be both sustainable and responsible, what is next? We are using the SRE normative framework in many of our HE classes (including those that are project-based) as we hope that by reinforcing this framework again and again, for different purposes and scenarios, our HE students will come to embrace it as a key dimension of what it means to be a humanitarian engineer.

In the summer of 2020 (and for the next 4 summers), we will be taking projects back to ASGM communities in Colombia and Peru for validation. Our new cohort (selected for 2020) of seven PIRE-RMRC undergraduate students will be researching the projects and the student teams of the 2019 PIRE-RMRC cohort as they learn community-based methods (participant observation, interviewing, surveys, participatory methods, etc.) in the HE course *Engineers Engaging*

Communities. This interaction between cohorts will allow for continuity in projects from year to year with the 2019 cohort, which focused on problem identification, and the 2020 cohort, which focused on validation of proposed designs. In addition, the 2020 cohort will also ensure that the implementation of these projects is guided by ESCD criteria (see section 5 above).

At the same time, our PIRE RMRC has created new institutional partnerships such as those with MIT D-Lab, whose team of entrepreneurial educators are delivering capacity building workshops for women in ASGM communities with the hope that they can enhance their income (thus enhancing Local Economic Diversity, ESCD criterion 1 above) by manufacturing some of the products that students and communities define together in the ECD Design Studio. For example, the 2019 cohort identified ergonomic backpacks to carry ore out of the mines as a need by ASGM miners to prevent back injuries. Currently, students are working on developing prototypes of such backpacks and considering how to use local materials and labor. The 2020 cohort will take such prototypes for validation to ASGM communities in summer 2020. If they are validated by ASGM miners then students can begin working with women miners in ASGM communities, now with the capacity to consider their own business creation thanks to the MIT D-Lab workshops, in the manufacturing of such backpacks. The long-term sustainability of these enterprises can be further ensured with the creation of Centers for Social Innovation by MIT D-Lab in ASGM communities [39].

10. Conclusion

As the number of engineering schools with initiatives (courses, projects, programs) related to community engagement continue to grow (see Figure 1), engineering educators need to embrace a more humble attitude towards the problems that we seek to solve. Instead of pretending that big problems like poverty or climate change have engineering solutions, we have to acknowledge that some of these problems might have no solution at all and instead focus our energies on improving the ability of communities to respond to these problems (resiliency). As the complex problem area of ASGM illustrated above shows, there might not be a solution to the poverty that serves as the reason for many people to become ASGM miners in the first place, or the poverty that ASGM continues to reproduce [18]. Hence, our job as engineering educators should be to educate our students to understand the limits of engineering solutions and perhaps direct their efforts to build resiliency in communities, using normative criteria such as SRE and ESCD criteria to guide their behavior and projects.

Furthermore, as community engagement initiatives grow, whether in the form of EWB student chapters [40] and projects or minors and certificates, engineering educators and administrators should create the appropriate institutional spaces where the theoretical, educational and practical (praxis) dimensions of these initiatives can co-exist and interact with each other. This paper illustrates one model in which these dimensions interact yet there must be others.

Throughout the development of our humanitarian engineering program, its courses and projects, and our multiple interactions with engineering educators, students and communities around the world, it has become increasingly clear that community engagement needs theoretical and normative frameworks to guide the action of our students as they engage communities (such as the SRE criteria above) and the expected outcomes of the their projects (such as the ESCD criteria above).

References

[1] K. L. Guzak, K. Paterson, and A. Archer, "A Comparative Assessment of Graduate versus Undergraduate Student Outcomes via International Community Engagement Programs," presented at the 2012 ASEE Annual Conference & Exposition, Jun. 2012, pp. 25.27.1-25.27.27, Accessed: Feb. 01, 2020. [Online]. Available: https://peer.asee.org/a-comparative-assessment-of-graduate-versus-undergraduate-student-outcomes-via-international-community-engagement-programs.

[2] J. Schneider, J. C. Lucena, and J. A. Leydens, "Engineering to Help: The Value of Critique in Engineering Service," *IEEE Technol. Soc. Mag.*, vol. Volume 28 Number 4, Winter 2009.

[3] D. Nieusma and D. Riley, "Designs on Development: Engineering, Globalization, and Social Justice," *Eng. Stud.*, vol. 2, no. 1, Mar. 2010.

[4] J. Lucena, J. Schneider, and J. A. Leydens, *Engineering and Sustainable Community Development*. San Rafael, CA: Morgan & Claypool, 2010.

[5] *Does America Need More Innovators?* .

[6] C. Struckmann, "A postcolonial feminist critique of the 2030 Agenda for Sustainable Development: A South African application," *Agenda*, vol. 32, no. 1, pp. 12–24, Jan. 2018, doi: 10.1080/10130950.2018.1433362.

[7] D. Moyo and N. Ferguson, *Dead Aid: Why Aid Is Not Working and How There Is a Better Way for Africa*. Macmillan, 2010.

[8] B. E. Goldstein, *Collaborative Resilience: Moving Through Crisis to Opportunity*. MIT Press, 2012.

[9] N. R. Council, D. on E. and L. Studies, B. on E. S. and Resources, G. S. Committee, and C. on P.-P. S. C. to E. C. D. Resilience, *Building Community Disaster Resilience Through Private-Public Collaboration*. National Academies Press, 2011.

[10] N. Salzman, B. Chittoori, S. Miller, and T. Robbins, "Senior Civil Engineering Students' Views on Sustainability and Resiliency," *2018 ASEE Annu. Conf. Expo.*, Jun. 2018, [Online]. Available: https://scholarworks.boisestate.edu/electrical_facpubs/395.

[11] C. C. Samuelson and E. Litzler, "Community Cultural Wealth: An Assets-Based Approach to Persistence of Engineering Students of Color," *J. Eng. Educ.*, vol. 105, no. 1, pp. 93–117, 2016, doi: 10.1002/jee.20110.

[12] *Collaborative Resilience*. .

[13] E. G. Callaghan and J. Colton, "Building sustainable & resilient communities: a balancing of community capital," *Environ. Dev. Sustain.*, vol. 10, no. 6, pp. 931–942, Dec. 2008, doi: 10.1007/s10668-007-9093-4.

[14] "Resiliencia. Descubriendo las propias fortalezas." https://www.elpsicoanalisis.org.ar/old/numero1/resilienciacomentario1.htm (accessed Feb. 01, 2020).

[15] M. Pieth, *Gold Laundering: The dirty secrets of the Gold trade - And how to clean up*. Salis Verlag, 2019.

[16] M. M. Veiga and B. G. Marshall, "The Colombian artisanal mining sector: Formalization is a heavy burden," *Extr. Ind. Soc.*, vol. 6, no. 1, pp. 223–228, Jan. 2019, doi: 10.1016/j.exis.2018.11.001.

[17] G. Hilson, “Small-scale mining and its socio-economic impact in developing countries,” *Nat. Resour. Forum*, vol. 26, no. 1, pp. 3–13, 2002, doi: 10.1111/1477-8947.00002.
[18] S. Siegel and M. M. Veiga, “The myth of alternative livelihoods: artisanal mining, gold and poverty,” *Int. J. Environ. Pollut.*, vol. 41, no. 3–4, pp. 272–288, Jan. 2010, doi: 10.1504/IJEP.2010.033236.
[19] J. A. Ruiz Córdoba, M. E. Carmona Arango, and W. Bolívar García, “Análisis del impacto ambiental generado por la emisión de mercurio desde fuentes fijas o entables del municipio de Andes - Antioquia,” *Instname Univ. Antioquia*, 2016, Accessed: Feb. 01, 2020. [Online]. Available: http://bibliotecadigital.udea.edu.co/handle/10495/5801.
[20] L. A. V. Restrepo, L. C. A. Patiño, J. V. Rueda, and A. R. Patiño, *Los planes de ordenamiento territorial municipal de Antioquia. Estudio del ideario.* Universidad Nacional de Colombia, 2013.
[21] K. M. Smits *et al.*, “Voces Mineras: Clarifying the future of artisanal and small-scale mining collaborations,” *Extr. Ind. Soc.*, Dec. 2019, doi: 10.1016/j.exis.2019.12.003.
[22] J. Smith and J. C. Lucena, “Socially Responsible Engineering,” in *Routledge Handbook of Philisophy of Engineering*, London: Taylor & Francis.
[23] “Normatividad - Minería en Colombia.” http://mineriaencolombia.anm.gov.co/index.php/es/normatividad (accessed Feb. 01, 2020).
[24] C. J. G. Colonia, *Brujería, minería tradicional y capitalismo transnacional en los Andes colombianos: el caso del pueblo minero de Marmato*. Instituto Colombiano de Antropología e Historia, 2017.
[25] libreriadelaU.com, “De oro están hechos mis días.” https://www.libreriadelau.com/de-oro-estan-hechos-mis-dias-hombre-nuevo-editores-9789588245843-novela-y-narrativa/p (accessed Feb. 01, 2020).
[26] E. E. Ferry and S. Ferry, *La Batea: Impressions of Gold in Colombia*. Red Hook Editions, 2017.
[27] “Leadership, Organizing and Action – Women & Subsistence Mining in Medellín, Colombia | MIT D-Lab.” https://d-lab.mit.edu/news-blog/blog/leadership-organizing-and-action-women-subsistence-mining-medellin-colombia (accessed Feb. 01, 2020).
[28] J. C. Bridger and A. E. Luloff, “Toward an interactional approach to sustainable community development,” *J. Rural Stud.*, vol. 15, pp. 377–387, 1999.
[29] W. Easterly, *The white man’s burden: why the west’s efforts to aid the rest have done so much ill and so little good*. New York: Penguin Books, 2006.
[30] S. Roy, G. R. Adhikari, and R. N. Gupta, “Use of gold mill tailings in making bricks: a feasibility study,” *Waste Manag. Res.*, vol. 25, no. 5, pp. 475–482, Oct. 2007, doi: 10.1177/0734242X07076944.
[31] W. McDonough and M. Braungart, *Cradle to Cradle: Remaking the Way We Make Things*. Farrar, Straus and Giroux, 2010.
[32] D. Laplonge, “The ‘un-womanly’ attitudes of women in mining towards the environment,” *Extr. Ind. Soc.*, vol. 4, no. 2, pp. 304–309, Apr. 2017, doi: 10.1016/j.exis.2017.01.011.
[33] M. C. Nussbaum, *Creating Capabilities: The Human Development Approach*. Harvard University Press, 2011.
[34] J. A. Leydens and J. C. Lucena, *Engineering Justice: Transforming Engineering Education and Practice*. John Wiley & Sons, 2017.

[35] W. E. Bijker, T. P. Hughes, and T. Pinch, *The Social Construction of Technological Systems*. Cambridge: MIT Press, 1987.
[36] M. Callon, “Society in the Making: The Study of Technology as a Tool for Sociological Analysis,” in *The Social Construction of Technological Systems*, W. E. Bijker, T. P. Hughes, and T. Pinch, Eds. Cambridge: MIT Press, 1987.
[37] H. Thomas and G. Santos (Sociologist), *Tecnologías para incluir: ocho análisis socio-técnicos orientados al diseño estratégico de artefactos y normativas*. Instituto de Estudios sobre la Ciencia y la Tecnología, IESCT, Universidad Nacional de Quilmes, 2016.
[38] “Engineering, Design, and Society < Colorado School of Mines.” https://catalog.mines.edu/undergraduate/programs/edns/#courseinventory (accessed Feb. 01, 2020).
[39] “Leadership, Organizing and Action – Women & Subsistence Mining in Medellín, Colombia | MIT D-Lab.” Accessed: Feb. 01, 2020. [Online]. Available: https://d-lab.mit.edu/news-blog/blog/leadership-organizing-and-action-women-subsistence-mining-medellin-colombia.
[40] B. Jaeger and E. LaRochelle, “Ewb^2 Engineers Without Borders: Educationally, A World Of Benefits,” presented at the 2009 Annual Conference & Exposition, Jun. 2009, pp. 14.597.1-14.597.23, Accessed: Mar. 14, 2020. [Online]. Available: https://peer.asee.org/ewb-2-engineers-without-borders-educationally-a-world-of-benefits.

Appendix A

The goal of this final paper is to revisit, apply and connect two cornerstones of this course: The criteria for Socially Responsible Engineering (SRE) and the criteria for Engineering for Sustainable Community Development (ESCD) to your chosen project. SRE is about YOUR attitude, knowledge and skills as an engineer working WITH communities. ESCD is about PROJECTS that might have a better chance to improve the living and working conditions of communities.

1. After having spent significant time in class revisiting and refining the SRE criteria, you are going to imagine yourself as an engineer **working in your VERY specific project in Andes, Antioquia**. You are expected to research the place further through videos, websites, radio stations, or by talking to Prof. Lucena, Alejo, Isabel, and others who have been there **(15 pts each X 4 = 60 pts):**

a. **Use the rainbow chart below to map stakeholders** to visualize which ones are the most impactful but less impacted (a reflection of power) and which ones the less impactful but most impacted (a reflection of lack of power). Describe the most important structural conditions (capitalist relations? Gender? Race? Others?) and power differentials to keep in mind among key stakeholders of your project (15 pts).
b. Now that you have a clear definition of contextual listening (see Leydens & Lucena in p. 22) and your stakeholder map, **what kinds of VERY specific activities would you design to**

contextually listen to all stakeholders, especially those who are marginalized, to grasp their needs, desires and fears surrounding your project? Explain how these activities have to be tailored to account for the differences in power among stakeholders (15 pts).

c. Now that you know that in order to collaboratively create shared social, environmental and economic value for relevant stakeholders, especially those who are marginalized, you can use your project to enhance different kinds of CAPITALS (social, human, environ, financial). **Use Callahan and Colton's framework (see below) to visualize and describe how different capitals will interact (and hopefully enhance each other) as related to your project**. Remember that this interactions between capitals is also linked to resiliency as "a resilient community is one that finds the appropriate balance of capitals within a particular community context." (Callahan and Colton, p. 939). (15 pts)

d. Specifically **describe how you will adapt engineering decision-making to promote those shared values (balance of capitals)**, acknowledging situations in which this is not possible to do so and engineering projects should not move forward. **Please be specific about engineering decision-making.** Remember that engineers build systems, processes, infrastructures, technologies, etc. that legislate, even after elected officials end their terms. (15 pts)

2. The last SRE criterion (*collaboratively assessing activities and outcomes with stakeholders*) can be addressed by using the ESCD criteria studied in class. Even though your project has not been built or put in practice with communities, you can begin to foresee (assess) how it might do with respect to the following criteria **(60 pts divided as follows):**
   a. **LOCAL ECONOMIC DIVERSITY (LED)**: **Creation of new products/markets** that protect local economy from global economic downturns; **Building, production, maintenance, distribution, etc.** based on local resources, processes, relationships, jobs; **Revenues reinvested** in local economy; **Capacity building and diverse job creation** that increase meaningful employment **(20 pts)**
   b. **POLITICAL AUTONOMY AND SELF-DETERMINATION**: **autonomy** in problem definition, problem solutions, & decision-making thereafter; **reduce dependency** from external capital, expertise, & decision-making; leveraged through **associative corporations (20 pts)**
   c. **REDUCTION OF ENERGY AND MATERIALS**: Design for cradle to cradle during building, repair, replacement; Reduce toxic and expensive materials while increasing non-toxic and affordable materials during building, repair, replacement; easy recycling and responsible disposal **(20 pts)**

3. Then using the definition of E4SJ provided in this class, also begin to assess your project. How does it fare with respect to: **(40 pts divided as follows)**
   a. **HUMAN CAPABILITIES**: See handout and Leydens & Lucena with brief descriptions of human capabilities. Briefly explain what human capabilities are directly relevant to your project. **You do not have to address every single one**, just the ones that are clearly relevant to your project. How could your project enhance or hinder these capabilities? **(10 pts)**

b. **OPPORTUNITIES**: what kind of opportunities will become available to community members because of the project? Will these opportunities be distributed more (or less) equally among community members? **(10 pts)**
c. **RESOURCES**: what kind of resources will become available to community members because of the project? Will resources be distributed more (or less) equally among community members? **(10 pts)**
d. **RISKS/HARMS**: what risks and harms will your project help reduce for the community? or will the project introduce new risks and harms in the community? **(10 pts)**

For all the papers in this class, I expect the following:

1. **An introductory statement** or thesis that serves as a focus or anchor to your subsequent paragraphs
2. Well developed, well-written, clear, persuasive and well-supported paragraphs in the middle, using class readings and additional sources from your research. **PLEASE USE THE QUESTIONS AS ORGANIZING SECTIONS to help the reader.**
3. A **conclusion stating your main finding, reflection, or critique** (or even an unresolved contradiction or tension that you might discover during your analysis and writing).
4. Incorporation and proper use of concepts and examples from readings and class lectures/discussions, **and proper citation using a consistent style.**
5. Avoid reader distraction by using correct spelling and grammar. **Avoid fluff and shallow words (e.g., stuff, thing, like)**
6. To help you keep focused on relevant content and analysis, your paper should have a **word length of 4500 words max (approx. 1500 per question)**. Please include a word count at the end of your paper.