



Quantifying and Qualifying the Preparedness of Engineering Students Collaborating with Underserved Communities Internationally

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Abstract:

Increasing globalization and technological innovations have redefined the role of engineers in working towards sustainable development. This is reflected in the creation and adoption of ABET Engineering Criteria 2000 which included six professional skills to prepare engineers who were more aware of how their profession, products and services are embedded in the larger global, socio-economic and political context. The question of how to measure and evaluate preparedness of engineering students to meet these requirements remains an open question.

This paper proposes a performance indicator called *global preparedness efficacy* to measure the effectiveness of curricula that bring student engineers together with underserved communities as a means to satisfying ABET criteria 3h, which is “the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.”

The paper describes a course curriculum that was developed to educate student engineers to work *with* rather than *for* underserved communities in rural India to design sanitation and hygiene solutions. What differentiates this course from other similar efforts is that the course curriculum requires students and community partners to articulate their personal connection to and *care* for the problem space, enabling a discourse that fosters collaboration as equals. In addition, the course curriculum provides a unique experience for student engineers to engage with community partners directly by using virtual communication technologies in order to incorporate the local historic, social, political and cultural context into their design solutions.

334 reflection journals collected from 16 students describing their engagement with the design process and collaboration with community partners (both virtually and in-person) are analyzed using a coding scheme to identify what curricular elements contribute to building *global preparedness efficacy*.

Introduction:

Increasing globalization and technological innovations have redefined the role of engineers in working towards sustainable development. This is reflected in the creation and adoption of ABET Engineering Criteria 2000 which included six professional skills to prepare engineers who were more aware of how their profession, products and services are embedded in the larger global, socio-economic and political context. The question of how to measure and evaluate preparedness of engineering students to meet these requirements remains an open question[1].

Responding to the ABET criteria and the growing consensus that engineers of the future should be trained to work in multicultural, global environments has lead to engineering education researchers investigating how to provide such learning environments. A 2011,

NSF sponsored study by Gary Downey in the book “What is Global Engineering Education For?” [2] captured the experiences of nine faculty members at nine different academic institutions about the challenges and rewards of initiating and sustaining global engineering efforts. The study showcased study abroad programs and courses offering local community service opportunities. All of the faculty while reflecting on their initiatives agreed, that global engineering education goes beyond the traditional engineering curricular efforts and that engineering students become “practitioners with an appreciation for difference “ and can “incorporate requirements from multiple cultures”[2 pp.16]. As a result, global engineering courses and projects have grown rapidly.

There has also been a simultaneous growth in engineering students looking for ways to use their engineering skills in service of improving the lives of those less privileged than them. Young students are eager to apply the engineering skills they are acquiring, to engage with these problems. This is echoed in the study conducted by Oberst and Jones on the megatrends in engineering practice, which identified social imperative as one of them [3]. As such, there has been a call for engineering educators to create opportunities for students to learn how “engineering is an integral part of societal change” and be able to accept “responsibility for civilization’s progress” [4].

A set of efforts responding to these demands is ongoing which Schneider, Lucena and Leydens have collectively called *engineering to help* (ETH). They have defined these as a diversity of programs that “hold as objectives the performance of some needed service and learning via reflection by those performing the service” [5]. However, they warn that such approaches do not often include the underserved communities as equal partners and may sometime cause more harm than good to the community. Despite the focus on community needs and equality, engineering projects often fail to effect lasting change and yield sustainable solutions. Using a case study approach, Nieusma and Riley were able to show how current paradigms of engineering projects in developing communities fail to meet the targets they set out to achieve: “The end result is a situation in which outsiders arrive with an agenda for change, they implement that agenda, and then they depart, fully intending that the host community will continue to follow their agenda” [6]. Achieving sustainable solutions by including the participating community as equal stakeholders while simultaneously ensuring student-learning poses a new and complex problem for educators.

Designing curricula that serve the community needs, serve student interest, and satisfy ABET criteria provide both challenges and opportunities.

Curricular Requirements:

There are several challenges in designing and implementing engagements with underserved communities. Identifying suitable community partners especially if they are NGOS is key. It is imperative to understand and examine their vision and values and learn through direct observation how they interact with the community. There is also the challenge of building trust with communities where personal exchange and relationship based transactions which are primarily face-to-face. In such communities, spending time and ensuring a long term-commitment is key. It is not within the scope of this paper to

investigate or outline prior research or best practices in community based research. The remainder of the paper will focus entirely on the challenges encountered by students in working with underserved communities globally.

Prior research shows that difficulties often arise as students arrive unprepared to address the cultural and technical challenges international work entails. For example, one particular case study in Gary Downey's book highlighted the challenges in implementation of a program to connect student engineers with underserved communities in an international setting. Differences in culture and language coupled with the geographical distance compounded made the project untenable and it had to stop. Some of the reasons she cited included that "the large body of knowledge in the development area was not readily accessible or available to engineers," and students did not actively seek out the ethical and social understanding necessary to work in such complicated settings [2, pp.162]. If these challenges could be overcome, creating curricula that allows student engagement with underserved communities could satisfy ABET criteria 3h, which is "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" [7].

In summary, the course curriculum should enable its students to appreciate the complexity of the problem space without feeling overwhelmed to address the problem and arrive at a solution in collaboration with the community. As such this requirement also lends itself to arriving at one way to evaluate such course offerings. A metric could be developed that would measure how well students navigate the obstacles they encounter due to the socio, cultural, economic, political, linguistic and geographical disparities between the underserved communities and themselves.

A Theoretical Framework To Understand Student Experience:

As students engage with challenging problems in the field, often their belief systems and confidence are challenged [8]. They have been described as "crucial and epistemologically-significant sites for transformation learning" [2, pp.4]. One approach to understand these experiences and the nature of challenges encountered by students brings together pertinent concepts and findings from Philip Zimbardo's Discontinuity Theory [9] and John Dewey's Theory of Inquiry [10]. This framework offers a view that the design process is punctuated by a series of 'discontinuity events' [8, p. 23] as points of inflections within the process that explained how designers experience challenges and possibilities for creative action.

A discontinuity as defined by Zimbardo is "a violation of the expectation in any domain of functioning highly valued self" [9, p. 351] It is an event that proves to be disruptive to the normal flow and pattern of everyday life. Zimbardo's theory offers nine types of "violations of expectations" (V.O.E) as sources of discontinuity, "each of which typically elicits characteristic affective reactions" including misfortune, good fortune, magic, miracle, humor and aesthetic value violation [9, p.351-352]. The nature of discontinuities is such that they are disruptive enough to cause an individual to seek an explanation for the experience in an attempt to restore either the previously experienced sense of normalcy or a renewed sense of self. Dewey's Theory of Inquiry proposes a mechanism

for how individuals encounter and attempt to resolve the doubts that cause discontinuities. Dewey defines Inquiry as the process of moving from a state of doubt to a state of belief or new knowledge [10, p. 7]. A discontinuity event therefore is defined as beginning with a violation of expectation resulting in a new belief or action, which can also be called, renewed action within the context of Deweyan inquiry process [8, p. 23-37].

Studying the discontinuity events encountered by the students during a course will serve as a metric to assess *global preparedness efficacy* (GPE) to navigate the disruption caused by the novelty and complexity of the problem space. Resolving a discontinuity empowers students to act in ways that reflect the growth and resilience needed to appreciate the complexity of a problem space and arrive at solutions. **The ratio of resolved to total discontinuity events will determine the *global preparedness efficacy*.** GPE offers a way to evaluate mastery of ABET criteria 3h in a systematic manner.

Research Setting

Data was collected from students taking the [name of the course] course at XYZ University. The program currently focuses on educating students to engage with the systematic, complex and existential problem of lack of sanitation and hygiene facilities faced by 2.6 billion people around the world [11]. The readings and discussions in the course address issues of education, safety, and dignity while enabling better hygiene and health monitoring by making the toilet desirable, affordable and the preferred alternative to open defecation starting with field sites in rural India. Over the duration of the course students learn how to work *with* the community by prototyping technologies to address some component of the problem.

This innovative approach was inspired by the book *Educating Engineers: Designing for the Future of the Field* by Sheri Sheppard et. al. where the authors state, “The shift from an outside to an inside perspective can be understood as a shift from engineering for “them” to engineering for “us”. Although this new point of view may be disarming, at the same time it holds the potential to inspire new thinking, for a shift from an outside to an inside perspective highlights the complex social, physical and informational interconnections” [12]. Instead of abstracting community problems out of their natural context and delivering solutions that would be difficult to integrate into the local culture, this approach explicitly encourages the community to contribute their local knowledge and expertise and participate in solving their problems in collaboration with the student engineers. The designing *with* approach is implemented by creating design teams that comprised of both student engineers and members of the underserved community who go through the design process together.

The class focuses on building the knowledge and skills necessary to build and maintain trusted relationships with community partners. The students and community members work as equals by articulating what is important to each member of the team and community in a way that transcends the traditional client consumer relationship. Student engineers actively reflect on their experiences as they develop a perspective that allows

them to make meaning of the complex problem space and use this complexity as a criteria for making design decisions.

The curriculum incorporates three unique elements that enable students to engage in the designing with process with community members as closely as possible and experience the realities of the field in a safe way. First, members of the community and NGO partners with extensive field experience are invited as guest speakers to the class using technologies for virtual communication. Second, the students are exposed to literature from multiple disciplines (Gender studies, Philosophy, Economics, Sociology, Philosophy, History etc.) to understand the complex context within which the problem is embedded. Third, the students are required to reflect on and articulate a care statement that describes what they care about within the problem space. This serves as the navigational tool to make design decisions [13]

Over the duration of 10 weeks, the students experienced the challenges of collaborating with an underserved community across geographical, cultural, economic and technological divides 12.5 time zones away. As part of the course, students regularly connect (a minimum of five virtual collaboration sessions, once a week for two hours each) with the community partners using technology of virtual collaborations. As such, many of the discontinuities that stem from course activities mirror those that are experienced in the field. The students were required to keep a reflection journal after every class related activity. These were the primary source of data. The data collected from student reflections was coded using the scheme discussed below

Data and Data Analysis

Over the course of 2 years, 334 reflection journals were collected from 16 students. Information about class demographics are presented in Table 1.

Year	Major	Gender	Year course taken
Senior	Mechanical Engineering	M	2014
Sophomore	Mechanical Engineering	F	2014
Sophomore	Human Biology	F	2014
Sophomore	Mechanical Engineering	M	2014
Freshman	Mathematical and Computational Sciences	F	2014
Sophomore	Mechanical Engineering	M	2014
Sophomore	Mechanical Engineering	M	2014
Sophomore	Mechanical Engineering	F	2014
Freshman	Mechanical Engineering	M	2014

Sophomore	Mechanical Engineering	F	2014
Sophomore	Mechanical Engineering	F	2013
Freshman	Undeclared	F	2013
Junior	Civil Engineering	M	2013
Sophomore	Product Design	F	2013
Junior	Civil Engineering	M	2013
Sophomore	Product Design	F	2013

Table 1: Information about students participating in course

Analysis of the student journals was done using a *discontinuity event* coding scheme that was developed as part of a doctoral thesis at Stanford University [8, p. 82-92]. The coding scheme identifies discontinuity events as per the following framework:

1. Articulation surprise or concern was coded as *discontinuity*
2. Evidence of understanding the discontinuity and commitment/actions to re-engage with the design process which were coded as *renewed action*
3. Explanations of what expectations had been violated and why it mattered to the designer were coded as *vulnerability*

A single journal entry can have multiple instances of discontinuity events. Each journal entry can be coded only once as well as each discontinuity event in a particular journal entry can also be coded only once. Each instance of a discontinuity event is marked up to differentiate between discontinuity, vulnerability and renewed action. The discontinuities were *italicized*, vulnerabilities were highlighted in **bold**, and renewed actions were left in plain text. The coded form of one discontinuity event from prior research is shown in the example below:

“I guessed that the left over work would take us 3 hours but it took us 5.5 hours. Ofcourse. Although I thought 3 hours was even an overestimate. I should remember to overestimate my overestimates by a factor of 2 for any kind of analytical or construction-based project. We had a bit of difficulty finding suitable, ball-bearing casters of an appropriate size, but we managed to figure out a way for it to work (get the smallest available casters so that they can fit on the 2x2” (1.5 x 1.5”) beams and drill holes into the beams for the neck of the casters to slide into.”
 [Student 1 Journal, August 22, 2009]

All coded data was put into tables for easy retrieval as shown below:

Date	22-Aug					
Page No.						
Discontinuity	I guessed that the left over work would take us 3 hours but it took us 5. course.					
Vulnerability	We had a bit of difficulty finding suitable, ball-bearing casters of an appr but we managed to figure out a way for it to work (get the smallest avai so that they can fit on the 2x2" (1.5 x 1.5") beams and drill holes into th the neck of the casters to slide into.					
Renewed Action	Although I thought 3 hours was even an overestimate. I should rem overestimate my overestimates by a factor of 2 for any kind of anal construction-based project.					

Table 2: Sample of Data Coding Format

Results

This coding scheme was used by two coders to identify discontinuity events in the journals entries of xx students who took the course in 2013 and 2014. The result of the analysis is shown in table below.

Discontinuity Events	130
Resolved Discontinuities	107
Unresolved Discontinuities	23

Table 3: Number of Resolved, Unresolved, and Total Discontinuity Events

Calculated GPE for the course was found to be 0.82.

To better understand what features of the curriculum contributed to the resolution of discontinuities (and a high GPE) a second analysis was conducted to identify the contributing factors to resolutions of discontinuities the source of renewed action. The following five categories emerged: the practice of care ethics, collaboration through Skype, class readings and discussions, team dynamics and relating to the prototype under production. Since discontinuities relating to team dynamics and prototyping are expected in any team-based, project-based class, these were grouped together and categorized as *other sources*. A summary of the data is shown in the table below.

	Care	Readings/Discussion	Skype Calls	Other	Total
Discontinuities	22	44	32	32	130
Resolved	20	33	24	30	107

Unresolved	2	11	8	2	23
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Table 4: Number of Discontinuity Events by Source

From the second analysis, it emerged that the curriculum provided students with the mechanisms for resolving these discontinuities that would inevitably result from engagement with underserved communities globally. To better illustrate this point the following section describes a few examples of how discontinuities were resolved because of the curricular features of the course.

Practice of care ethics

It appeared that learning the practice of designing with care equipped students with the outlook to overcome feelings of being overwhelmed or frustrated by the complexity of the problem space. For example, one student wrote: *“asking what is most important to us brings clarity by moving from feeling controlled by the desire to help bring a certain change or achieve something, and instead empowers us to align our efforts and move toward doing that thing (or recognize we need to expand our care-circle in order to continue).”* Having a care statement creates a framework to contextualize feelings of frustration or surprise and move forward in a way that is consistent with the student’s values and provides a sense of direction. The idea for designing with care also helped students value the role of their own passions in arriving at a sustainable solution. For instance one student reflected that: *“I feel like the biggest thing I learned is that the designing process should not just be designing for someone else but it is okay to combine what you care about with what they care about. By doing that I feel like you are able to create much more so a relationship of mutual trust to reach a common goal.”*

Collaboration through Skype

Virtual face-to-face collaboration with the community partners helped students gain a better understanding of the problem space and see the designing with care process in action. Skype calls helped students resolve discontinuities related to the readings and incorporate the feedback of the field experts into their designs. Several students described that hearing from experts in the field helped give direction to their design solutions. For instance, one student described that sharing their design, *“gave [their] team confidence in [their] idea, but also a good list of constraints to work with and possible issues to think of. Overall, the Skype call was extremely helpful and made [him] excited to continue working on [their] project.”*

Engaging with community partners helped students reflect on how engineering with care serves as a approach to engaging with complex issues. As one student reflected, *“[a]lthough [the guest speaker’s] anecdotes were most definitely eye-opening, it made me realize once again just how multivarious a complete solution must be. Every village, every region has its own cultures and constraints – what works in some places won’t work in others. Rather than discouraging our efforts, this fact should actually encourage us to appreciate the wide diversity of the expression of human nature.”*

Interaction with community leaders provided tangible examples of ways that students could appreciate but not be overwhelmed by the difficulties of working in the field.

The process created an avenue for the students to contextualize how their roles and values complemented the needs and values of the partner organization. One student's pleasant surprise about the nature of the collaboration encouraged her to reevaluate her role in the project *"Today we skyped with the people in India, and I am amazed by the love that filled the call. Not only did we begin with prayer, but we also considered each other family. The love and care that surrounded the call calmed my doubts about our role in this project. They seemed excited for us to care about their space, and they weren't opposed to our engineering projects."*

Class readings and discussions

Introducing students to multiple perspectives on sanitation and hygiene helped students reflect on difficult issues that often come up in development work and build confidence that they could address these challenges.

For instance, students read a chapter titled *Geographies of danger: School Toilets in sub-Saharan Africa* describing issues of sexual assault and personal safety at toilets in schools [14]. This issue is indicative of the challenging emotional experiences that students realistically may encounter in the field. The context of the class discussion facilitated learning by allowing students to safely share their feelings and discuss ways to incorporate their reactions into designing a better solution in collaboration with people who may experience such challenges. This example shows the progression of thought from shock to action in one student *"I was very taken back by the Geographies of Danger paper, in which issues of girls specifically facing the danger of rape when going to the bathroom in sub-Saharan Africa. This was extremely alarming for me, as safety has never been an issue that I would consider when going to the bathroom. For our toilet design, it might be interesting to think about how to cater the toilet to each specific gender using it so that both are comfortable."*

Often, the student's reflections led to a resolution to continue to act beyond the scope of the course. After learning about the effects of cultural taboos surrounding menstruation in *The Flush Alternative for the Women of Soshanguve* by Nonhlanhla Mjoli-Mncube [15], many students were initially disturbed by the problem, but eventually arrived at possible solutions. After reflecting on the difficulty faced by women during menstruation, one student reflected that *"It would be difficult to get women to change their behavior and be ok with the fact that something unclean is being kept inside of them, however, perhaps the need for a sanitary napkin that does not need to be disposed of (and thus a cause of public shaming) could overcome this discomfort."* This led her to thinking that *"I want to consider making a diva cup in one of my ME [Mechanical Engineering] classes for developing countries, I know there is one specifically that teaches you to make products out of silicone- perhaps there is some kind of safe and cheap material that could work. This would be a very difficult- and brave- project to take on...but might be interesting."*

Additionally, discussions based on the field of global engineering education more broadly also led students to question their beliefs and translate their doubts into paths to action. After reading *Engineering to Help: The Value of Critique in Engineering Service* [5], one student reflected “*I really like the idea of this approach, as it makes it possible to stay focused and working towards some change or progress, rather than merely spiraling in a circle of guilt. I’ve personally really enjoyed this class, as I often feel like I learn a lot of facts that make me feel guilty and am never sure how to act, but haven’t felt this as much in this course.*”

Conclusion and Future Work

This paper is a preliminary effort to develop a metric that measures preparedness of engineering students in accordance with ABET criteria 3h [7]. Global preparedness efficacy is developed from a theoretical framework to look at student experiences as discontinuity event and is defined as the ratio of resolved to total discontinuities encountered. This metric can be further developed to evaluate the efficacy of different curricula in improving student experience across many different international contexts. The paper goes on to describe a discontinuity event coding scheme and its application to the GEE course. In doing so it emerged that the unique curricular features of GEE are successful in enabling students to navigate the unpredictable and novel context of collaborating with underserved communities as evidenced by its GPE of 0.82. This instrument can be used to further track progress and critically examine the efficacy of each curricular component.

As new iterations of the course are offered, a pre and post evaluation will be conducted to monitor the development of efficacy throughout the course. Also, the role of the relationships between the three unique curricular components of the GEE curriculum in creating efficacy will be explored further. By applying the coding scheme used to other curricula, alternative curricular components that contribute to a higher GPE will be suggested. Perspectives from other disciplines will be implemented to extend the applicability of GPE to assessing the student experience in other educational contexts. Currently research is being done to thoughtfully identify appropriate methods to measure the impact of the program from a community perspective with the aim of improving the quality of collaboration.

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