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Aligning learning objectives and approaches in global engineering graduate programs: Review and recommendations by an interdisciplinary working group

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A B S T R A C T

Despite decades of global development programming, poverty persists in the low-and-middle-income countries targeted by these efforts. Training approaches to global development must change and the role of engineers in these efforts must evolve to account for structural and systemic barriers to global poverty reduction. Rapid growth in Global Engineering graduate programs in the United States and Canada creates an opportunity to unify efforts between academic institutions and ensure that programs align with the sector's needs as identified by practitioners. To build consensus on how to equip engineering students with the knowledge, skills and attitudes necessary, we convened practitioners, faculty and graduate students for a two-day workshop to establish an agreed-upon Global Engineering body of knowledge. The workshop was informed by a pre-event survey of individual participants and representatives of participating academic institutions with graduate programs in Global Engineering or a related field. Through the workshop breakout sessions and post-event work by the authors, we developed the following priority learning objectives for graduate education in global engineering: Contextual Comprehension and Analysis; Cross-cultural Humility; Global Engineering Ethics; Stakeholder Analysis and Engagement; Complex Systems Analysis; Data Collection and Analysis; Data-driven Decision Making; Applied Engineering Knowledge; Project Design; Project Management; Multidisciplinary Teamwork and Leadership; Communication; Climate Change, Sustainability, and Resilience; Global Health; and Development Economics. Although technical skills are central to preparing the next generation of Global Engineers, transversal and interdisciplinary skills are equally important in equipping students to work across sectors and account for barriers to global development and equity.

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1. Introduction

Despite decades of global development programming, poverty persists in the low-and-middle-income countries targeted by these efforts and climate change threatens to undo any progress that has been made. Almost half of the world's population still subsists on less than $5.50 a day ("Nearly Half the World Lives on Less than $5.50 a Day," 2018); environmental health issues still drive disease in low-income countries ("GBD Compare," 2019); and climate change still has undeniable, negative impact on people, especially in low- and middle-income settings and underserved communities (Levy and Patz, 2015). Historically, engineers approached this role through technology design and development, and technical interventions at the community, regional or national scale. These approaches have proven inadequate and sometimes inappropriate, as they fail to address—or even acknowledge—the structural constraints and global systems that perpetuate poverty. Therefore, approaches to global development must change and the role of engineers in these efforts must evolve (Thomas, 2019; Thomas & Amadei, 2010; Thomas and Brown, 2021).

The practice of Global Engineering can prepare the next generation of engineers to address structural and systemic barriers by teaching them to solve engineering problems collaboratively in lower-resource settings, and equipping them to account for socioeconomic, environmental and political constraints. This next generation of Global Engineers will lead the development and validation of the tools, policies and practices needed to support the public, private and non-profit sectors in improving livelihoods worldwide. Existing efforts by academic institutions to educate Global Engineers present an opportunity to create an agreed-upon body of knowledge for Global Engineering, and to improve upon past efforts while accounting for the evolution that engineering must undergo to assist in global poverty reduction.

In February 2021, the Mortenson Center in Global Engineering and the Environmental Engineering program at the University of Colorado Boulder (UCB), in collaboration with the University of Michigan and the American Society of Mechanical Engineers (ASME), hosted a workshop to generate consensus on the emerging field of Global Engineering and to establish learning objectives (Marzano, 2010) for Global Engineering graduate education and programming in the United States and Canada. This workshop brought together faculty, students and staff from 38 North American university programs, and practitioners from 17 organizations engaged in Global Engineering. Over two days, participants took part in structured working sessions, discussed existing curricula in graduate and undergraduate programs, brainstormed and refined learning objectives to incorporate across graduate programs, and discussed how to achieve these objectives.

This paper results from pre-workshop surveys, workshop sessions and further work by the volunteer writing committee to consolidate the discussions and provide information on each learning objective to create a body of knowledge that establishes the field of Global Engineering. As authors representing fourteen academic institutions, we acknowledge that preparing the next generation of globally responsible engineers will require: (1) curricular rigor equal to that of any other engineering discipline and (2) cross-training engineers in other, more established development disciplines, such as global health, public policy, economics, business, and social sciences (Nilsson et al., 2014).

Together, we studied the question: *What is the graduate level body of knowledge in Global Engineering that can equip students with the context, skills and attitudes to practice global development equitably and systemically?*

The scope of this National Science Foundation-funded workshop was limited to graduate education in North American universities. We chose this inclusion criteria deliberately in recognition of the relative similarities in the structure of these graduate programs and the career opportunities afforded to these students. However, we recognize that Global Engineering in academia is not restricted to education, nor is Global Engineering education restricted to North America. We also acknowledge the importance of undergraduate education and of research to the field of Global Engineering. And while, the focus of this workshop was purposely narrow, the intention is that the knowledge, collaboration and outcomes shared will contribute to advances in education and research globally.

2. Background and motivation

As laid out by Thomas et al. (2021), the emerging field of Global Engineering represents an evolution in how engineers address global development inequities and challenges. As such, Global Engineering builds on approaches to engineering education laid out over the last decade, including Development Engineering (Nilsson et al., 2014), Humanitarian Engineering (Park et al., 2021), and Peace Engineering (Amadei, 2019). In setting forth the field of Global Engineering, the intention is not to supplant these, or more established fields such as global health or development economics, but to learn from them and establish common ground. It is necessary, therefore, to engage academic stakeholders across these disciplines in working toward a consensus body of knowledge for Global Engineering.

An inclusive definition of Global Engineering was proposed by Thomas et al. (2021) as, "We define Global Engineering as concerned with the unequal and unjust distribution of access to basic services such as water, sanitation, energy, food, transportation and shelter, and places an emphasis on identifying the drivers, determinants and solutions toward increasing equitable access to reliable services. Global Engineering envisions a world where everyone has safe water, sanitation, energy, food, shelter and infrastructure and can live in health, dignity, and prosperity.

We advance that Global Engineering can therefore be the professional and academic complement to Global Health and Development Economics—focused on broadly improving the tools and practice of poverty reduction, and deliberately including health, economics, policy, and governance as relevant dimensions, and requiring our professionals to be conversant in these fields."

Global Engineering programs including degree programs, concentrations and certificates have proliferated over the last two decades. These offerings focus on equipping engineering students with the knowledge, skills and awareness to address persistent poverty and respond to crises in low-resource settings. While these programs share a common goal in training engineering students to engage in global poverty reduction, surveys of their offerings reveal a wide range of pedagogical approaches and curricular content. There is an opportunity, therefore, to bring programs together to develop an agreed up on set of learning objectives and to work toward consistency in approaches to achieving them, with the goal of increasing the collective impact of these programs and their graduates.

Among recent assessments, a 2020 review examined 67 engineering programs focused on preserving life and alleviating human suffering. This review found that most programs included an experiential component required of all students (Smith et al., 2020). Experiential requirements like study abroad, project-based learning and service learning provide students the opportunity to acquire field experience, viewed as essential to preparing them for a career in the sector (Passino, 2009). Beyond this field experience, research shows that project-based and service learning support students' attainment of standard engineering competencies (Mintz et al., 2014; Smith et al., 2020), their ability to work on teams, and development of their self-awareness, empathy and cultural sensitivity (Birzer and Hamilton, 2019).

But while experiential learning through field-based opportunities appears to be one point of consensus among programs, the same cannot be said about other elements. For example, a review of research publications at the intersection of mechanical engineering and engineering for global development found a lack of consensus on technical terminology between various degree-granting service-learning programs. As these programs represent a growing part of the engineering education landscape, the authors suggested that the variety of nomenclatures might confuse potential students comparing programs and inhibit cross-institution collaboration. Additionally, they posited that this problem would increase when including other engineering disciplines that address international development, such as civil, environmental, and electrical engineering (Burleson and Austin-Breneman, 2020).

Outside of North America, several organizing bodies call for the standardization and professionalization of programs and approaches in fields like Global Engineering to ensure quality of service by and increase public recognition of given occupations (Hoyle, 2001). For example, the Humanitarian Action Qualifications Framework, developed by the European Universities on Professionalization on Humanitarian Action Project to ensure the quality of education on and delivery of humanitarian assistance, establishes learning outcomes for different qualification levels in the humanitarian sector. Similarly, the Humanitarian Engineering Education Network of Australasia (HEENA) was established in 2017 to support the growth of Humanitarian Engineering educational programs in the region. HEENA's priorities for strengthening and growing the field and its impact include expanding educational research and development, engaging with professional bodies and participating in advocacy. In addition to HEENA's efforts, the Australian Council of Engineering Deans (ACED, 2018) calls for the professionalization of Humanitarian Engineering to ensure appropriate practice. More recently, the International Engineering Alliance revised its graduate attributes and professional competence profile for engineers to incorporate the Sustainable Development Goals, acknowledging the contributions that engineers make to achieve these goals (*Graduate Attributes and Professional Competences*, 2021). These few examples are far from exhaustive.

Given the range of educational offerings, defining methods and approaches across programs is necessary to ensure consistency in educational outcomes and application of appropriate and ethical development practices (Smith et al., 2020). To support the professionalization of the global development sector and in particular the role of engineers in this sector, it is necessary for the field of Global Engineering to establish a consensus body of knowledge that will equip students with the knowledge, skills and attitudes to improve development tools, policy and practice. This will require engaging a diverse set of stakeholders in Global Engineering and related fields.

In parallel to formal engineering education, organizations like Engineers without Borders-USA, Engineers for a Sustainable World, and Engineers in Action give engineering students and professionals opportunities for volunteer work in lower-resource settings in the United States and abroad. While these opportunities contribute to professional training for engineers (Bourn and Neal, 2008; Litchfield et al., 2016), this approach is increasingly seen as insufficient for training globally responsible engineers (Mintz et al., 2014). Further, these activities can inadvertently exploit and harm local communities for the sake of training students (Birzer and Hamilton, 2019). These and other organizations need to be included in efforts to introduce technical rigor and historically contextualized, interdisciplinary training at the curricular level and in extracurricular work.

This paper describes how we brought together a diverse set of stakeholders to discuss the question: *What body of knowledge does graduate education in Global Engineering need to equip students with the knowledge, skills and attitudes to address structural and systemic barriers to global development and equity?* The process included identification of participants to ensure engagement across disciplines and experience, pre-event participant input to inform the workshop, workshop breakout sessions to generate the list of priority learning objectives, and writing committee work to develop these learning objectives and propose approaches to achieve them. This paper then presents the results of our work, beginning with participant input through pre-workshop surveys, followed by the body of knowledge initiated during the working sessions and developed by the writing committee after the workshop.

3. Methodology

As stated, the workshop and subsequent work focused on graduate Global Engineering education at North American academic institutions. The workshop focused even more specifically on 12 to 15 semester credits, which could serve as the core of a Master's or fulfill the requirements of a graduate certificate, the latter representing completion of specialized training at the graduate level. In recognition that every program will be different, focusing on a set of credits supported consensus building around that core while allowing for flexibility outside of it.

The workshop's intended short-term output was a list of learning objectives for graduate education in Global Engineering, with discussion on how to achieve these objectives leading to a medium-term output of a consensus body of knowledge comprising learning objectives, Bloom's taxonomy (*exposure*, *competency* or *mastery*), and approaches. These outputs and the processes for achieving them built upon the work by Thomas et al. (2021), which shared the UCB Mortenson Center in Global Engineering's learning objectives and body of knowledge. The intent was to move beyond an individual institution's body of knowledge to one agreed upon and enacted by many institutions across North America. Fig. 1 summarizes the timeline and inputs to achieve these outputs and identifies the contributors to each step in the process.

A multi-method approach (including pre-workshop surveys, small-group discussion and voting, and large-group sharing and discussion) was used to establish the learning objectives and begin discussion of how to achieve them. This work carried forward asynchronously through writing sub-committees made up of volunteers from the workshop, and the complete set of learning objectives and approaches to achieve them was circulated to all writing committee and organizing committee members for review and comment. The steps of this further detailed in subsequent sections and are summarized in Fig. 2.

3.1. Participants

The six-member workshop organizing committee, made up of representatives from the Mortenson Center, the University of Michigan and ASME generated an initial list of invitees to the workshop. All three institutions had recently conducted and published research on Global Engineering Pedagogy (Thomas et al., 2021) and Engineering for Global Development (Burleson and Austin-Breneman, 2020; Peiffer, 2019) that included desk research on academic institutions engaged in these fields. Further input on potential invitees was obtained from the Mortenson Center's students and advisory board. Online research identified several additional institutions engaged in Global Engineering or related education. Specific individuals were identified for each institution where possible. Not including the organizing committee, the resulting invitation list comprised 84 individuals: 56 faculty members from 40 academic institutions, and 28 practitioners from 20 organizations engaged in Global Engineering, including membership organizations, engineering consulting firms, U.S. government agencies, non-profit organizations, and funders. The faculty members invited were asked to nominate a graduate student from their institution to also attend. Ultimately, the workshop brought together representatives from 38 North American academic institutions and 17 organizations. Not counting the organizing committee, attendees included 49 faculty, 42 students and 24 practitioners. Appendix A provides the list of represented universities and organizations.

3.2. Pre-workshop surveys

As part of the engagement process, surveys developed by the organizing committee were sent to faculty, students and practitioners invited to attend the workshop. These were sent out in December 2020, two months before the workshop, to gauge planned attendance and to collect input on: (1) learning objectives for preparing students for a career in

Fig. 1. Workshop timeline.

Global Engineering; (2) the most important skills for work in the global development sector; and (3) knowledge and skills missing from current graduate programs in Global Engineering. This input was summarized and shared with respondents for review before the workshop, to serve as a starting point for discussion.

Faculty members who indicated an intent to attend the workshop were asked to recommend a graduate student attendee from their institution who was completing a degree in or conducting research on Global Engineering or a related field. Surveys were sent to these graduate students too. In addition to asking whether a respondent planned to attend the workshop, the survey asked them a set of questions, depending on the respondent group. Table 1 presents these questions, which were open ended with the exception of the rating of learning objectives.

The faculty survey asked respondents if their academic institution had a department, program or center focused on graduate education in Global Engineering or a similar field. Those who responded affirmatively were sent a follow-up survey that asked for a summary of their university's graduate education, list the courses offered and describe the experiential element (i.e., internship or field placement), if included. Respondents were also asked: (1) how the program addresses diversity, equity and inclusion; and (2) if and how the program includes critical discussion of the history of international development. The responses were used to prepare a landscape document, shared as part of the pre-workshop materials, which participants were asked to review before the workshop. They were also used to identify presenters for the short talks on the first day of the workshop.

The learning objectives that students and practitioners were asked to rate on a 5-point Likert scale were those published in Thomas et al. (2021), which are the primary learning objectives for the Graduate Certificate in Global Engineering offered by the Mortenson Center. These were developed by the Mortenson Center based on feedback from students, faculty, staff and Advisory Board members. Their development was based on Bloom's Taxonomy, which can help design curriculum maps, plan lessons and create assessments (Anderson and Krathwohl, 2001). Table 2 presents the fourteen learning objectives. Student and practitioner respondents were asked to rate these on the Likert scale as "Extremely important", "Very important", "Moderately important", "Slightly important" or "Not at all important". A summary of the rating results as well as important and missing skills and abilities was provided as part of the pre-workshop materials.

3.3. Workshop agenda

The workshop agenda as developed by the organizing committee was initially designed for an in-person workshop. Due to COVID-19, the workshop format was changed to remote, and the scope of the workshop and the agenda had to be more narrowly defined and revised to account for virtual participation. To maintain engagement, most of the workshop was spent in breakout sessions with groups of 8–10 people, a facilitator and a graduate student assistant facilitator. Each day before the breakout session, participants attended talks that provided context for

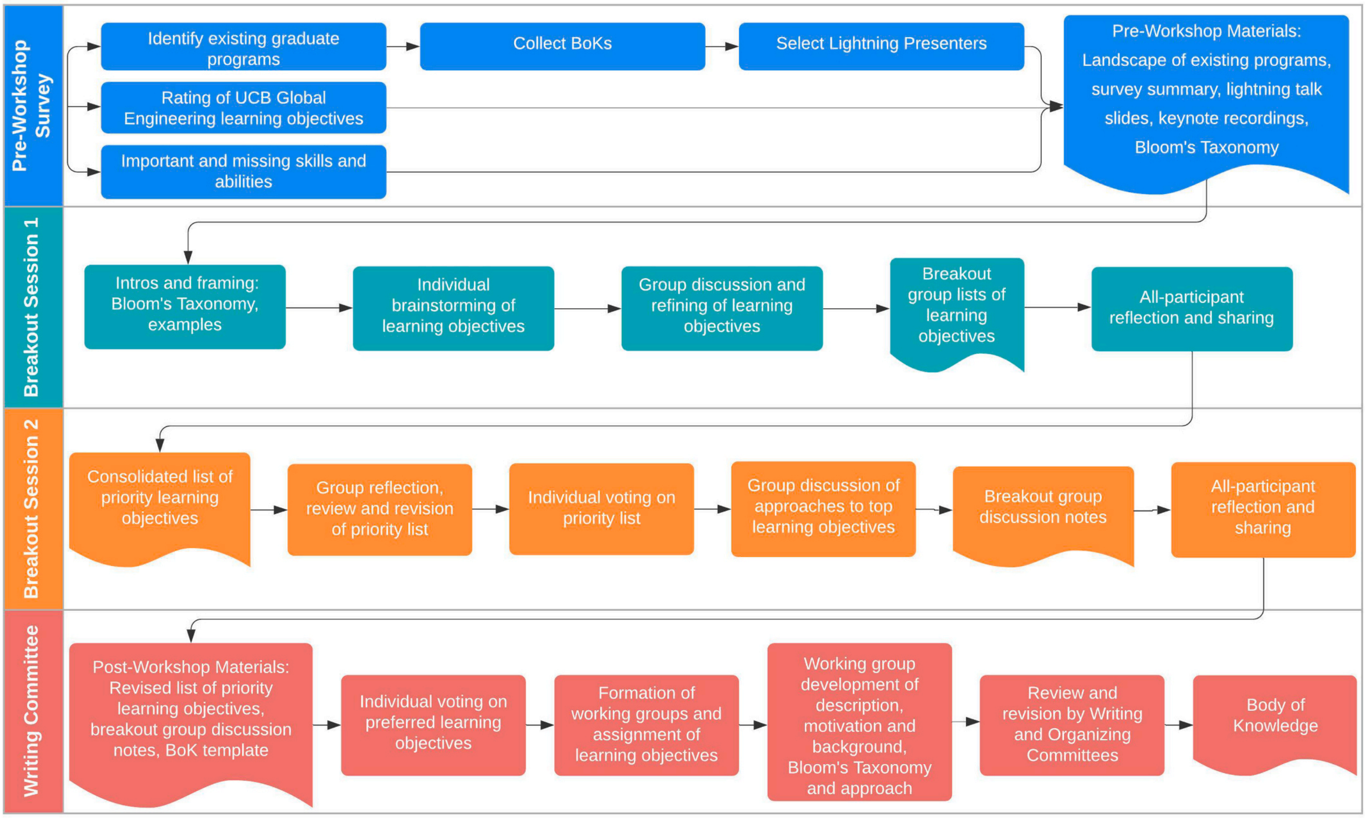

Fig. 2. Methodology.

Table 1
Survey questions by respondent group.

Respondent group	Questions
Faculty	• Graduate program information • Most important skills/abilities that graduate students need to work within the global development sector
Students and practitioners	• Rate the importance of provided learning objectives for a Global Engineering graduate program. (5-point Likert scale) • Most important skills/abilities to work within the global development sector • Skills/abilities that are missing from current graduate programs in Global Engineering (or related fields)

Table 2
Mortenson center graduate certificate – primary learning objectives.

1	Analyze the historical and contemporary context of global inequalities and global development poverty alleviation policies, programs, institutions, and social movements
2	Identify and explain security, public policy, governance and rights-based approaches to global development
3	Identify and apply relevant engineering skills toward global development
4	Identify and explain social entrepreneurship applied in global development
5	Identify and explain the professional field of Global Health
6	Identify and explain the professional field of Development Economics
7	Identify and explain systems thinking methods and approaches
8	Identify and explain project management skills and methods
9	Implement qualitative and quantitative data collection and analysis within a global development application
10	Apply technical interventions designed to support global development
11	Apply methods for programmatic impact evaluation
12	Apply important dimensions of professional field readiness
13	Recognize cultural differences and apply skills to collaborate across cultures
14	Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks and meet objectives

the discussion for the day. On Day 1, a pre-recorded plenary talk by Evan Thomas (CU Boulder) focused on the questions: *What is Global Engineering? What is its role in contributing to global poverty reduction?* "Lightning" talks afterward gave examples of programs' existing approaches to graduate education in Global Engineering. Based on the depth of their responses to the pre-workshop survey, representatives from the following institutions were asked to give short talks about their graduate programs: Colorado School of Mines, Massachusetts Institute of Technology, University of California Berkeley, University of South Florida and University of Colorado Boulder. Appendix B provides summaries of these presentations. On Day 2, a pre-recorded interview with Jack Colford (University of California Berkeley) focused on the question: *How do academic institutions prepare students to be practitioners in an emerging field?* Question and answer sessions followed each day's plenary talks to engage participants and begin to focus the conversation. The detailed workshop agenda can be found in Appendix C.

3.4. Breakout sessions

Breakout groups were separated by participant type—faculty, students and practitioners—and were the same for both days. The organizing committee discussed whether to mix participant types in groups to allow for exchange of ideas between types but ultimately decided to separate participants by type to facilitate ease and comfort of participation, specifically for graduate students. Groups were kept the same between the two days for efficient use of time.

The aim of the first breakout session was for participants to generate a list of proposed learning objectives drawing on their experiences and on the opportunities and challenges laid out in the plenary talk.

Development of these objectives was informed by Bloom's Taxonomy, which provides a common set of verbs: "remember", "understand", "apply", "analyze", "evaluate" and "create" (Anderson and Krathwohl, 2001). Facilitators provided example learning objectives using these verbs, then participants individually brainstormed potential objectives in a shared document. After the brainstorming, participants came together to combine and refine the objectives. Assistant facilitators took notes on the discussion and revisions to the learning objectives in the shared document. All groups then came together during the closing session of the first day and representatives from half were asked to reflect on the process and share their takeaways. Following this closing, subgroup of the organizing committee reviewed the lists of learning objectives from the breakout groups to come up with a consolidated list.

The following day, the consolidated list of learning objectives served as the launch point for the second breakout session. This session's goal was to produce a further refined and prioritized list of learning objectives. To that end, participants reviewed the consolidated list, identified elements missing from those learning objectives and/or missing learning objectives that the group thought should be prioritized, voted on the top objectives and discussed approaches to achieve each one. Assistant facilitators again took notes on learning objective revisions and discussion of recommended approaches in the shared document. Representatives from the groups that did not share feedback the previous day were asked to share their group's top learning objectives and takeaways from the discussion of how to achieve them. After the workshop closing, the organizing committee's subgroup came together again to review and consolidate the breakout groups' lists, incorporating notes and comments from the second session. This resulted in a list of 15 priority learning objectives.

3.5. *Writing committee*

The organizing committee asked participants if they wanted to be a part of a writing committee that would carry forward the list of learning objectives to build a consensus body of knowledge around these objectives. This resulted in a 22-person writing committee, comprising 13 faculty, two practitioners and seven students. These participants were asked to indicate three learning objectives that most interested them, which resulted in six working groups ranging in size from two to five members. Depending on the number of members, each group was assigned to work on one, two or three of the learning objectives.

The working groups were given a template to support parallel construction and content across learning objectives. The template contained the following sections: learning objective description; motivation and background; Bloom's taxonomy; and approach. Most working groups split into pairs to work on individual learning objectives, then exchanged documents for review and comment by others in the group. Members of the organizing committee then reviewed and revised the completed drafts based on their areas of expertise. The authors of this paper were members of the organizing committee and/or the writing committee.

4. Results

This section presents summary results from each step of this process, with the full details for each learning objective provided in Appendix D.

4.1. *Pre-workshop survey*

There was a high overall response rate across respondent groups, with 67% of faculty invitees, 89% of student invitees and 62% of practitioner invitees responding to at least part of the survey. Despite some drop off over the course of the survey, the results presented here capture the input of many individuals in different positions across a wide range of institutions engaged in Global Engineering and related fields.

Of the 38 faculty who responded, 16 reported that their institution had a department, program or center focused on Global Engineering or a similar field, at either the undergraduate or graduate level. For reference (Peiffer, 2019), reports that there are 32 higher-education institutions in the U.S. and Canada that offer global engineering related programs and/or research: undergraduate degrees (3); graduate degrees (8); minors, certificates and degree specializations (14); coursework (29 institutions); research centers (28 institutions); and experiential opportunities (22 institutions). Among the 16 represented entities, the number offering each type of graduate program in Global Engineering or a related field breaks down as follows: course-based MS (6); thesis-based MS (6); graduate certificate (6); PhD (6); Other (5); No graduate programs offered (4). Responses to "Other" included a Peace Corps Fellows program, dual-degree programs, a standard engineering degree with a research focus on humanitarian engineering, and Global Engineering being specific to one respondent's research group. A follow-up survey was then sent to the ten faculty respondents who indicated that their institution offers graduate education (course-based MS, thesis-based MS, graduate certificate, and/or PhD) in Global Engineering or a related field. Table 3 lists these universities, their programs and graduate offerings.

4.2. *Rating learning objectives*

Asking student and practitioner respondents to rate the importance of the Mortenson Center's Graduate Certificate learning objectives was intended to gauge participant opinions before the workshop and to serve as a springboard for discussion during the workshop. There was general agreement on the importance of the 14 learning objectives. All learning objectives were rated as at least "moderately important" (3 out of 5 on the Likert scale) by 80% or more of student respondents (n = 30) and by 89% or more of practitioner respondents (n = 18). There was alignment in the learning objectives considered to be "extremely important" by most graduate students (57% or more) and practitioners (61% or more). These learning objectives were: recognize cultural differences and apply skills to collaborate across cultures; identify and apply relevant engineering skills toward development; and function effectively on a team

Table 3
Participating Institutions with Graduate Programs in Global Engineering and/or a Related Field.

University	Name of program	Graduate offerings
Arizona State University	Global Technology & Development/Innovation in Global Development	MS and PhD programs
Colorado School of Mines	Humanitarian Engineering Program	Course-based MS, thesis-based MS, PhD
Drexel University	Peace Engineering	MS program
Massachusetts Institute of Technology	Global Engineering and Research Laboratory, Abdul Latif Jameel Water and Food Systems Lab, D-Lab	Research group with graduate degree related to Global Engineering, thesis-based MS, PhD
Oregon State University	Humanitarian Engineering Program	Standard engineering degree with humanitarian research focus
University of California, Berkeley	Development Engineering, founded by the Blum Center for Developing Economies	MS includes courses, internship, and capstone project, designated Doctoral emphasis
University of Colorado Boulder	Mortenson Center in Global Engineering	Professional MS, thesis-based MS, graduate certificate, PhD
University of South Florida	Engineering for International Development	Thesis-based MS, graduate certificate, PhD, Peace Corps fellows program
University of Toronto	Centre for Global Engineering	MS emphasis in Engineering and Globalization
Villanova University	Center for Humanitarian Engineering and International Development	MS/PhD concentration in Sustainable International Development

whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks and meet objectives.

4.3. Qualitative responses: skills and abilities

All respondents were asked open-ended questions about the skills and abilities they consider most important for working in global development, and students and practitioners were asked what skills and abilities were missing from current Global Engineering graduate programs. Faculty were again asked for less input in this survey, awaiting the follow-up survey of body-of-knowledge questions about their institutions' graduate programs. These open-ended questions were used to understand the different perspectives of faculty, students, and practitioners, and identify key themes and gaps to inform the workshop's agenda.

Participant responses were reviewed by the first author to identify key groups of skills and abilities through inductive qualitative coding. The following groups were identified as important by at least 20% of two of the three respondent types (27 faculty, 30 students, 15 practitioners): cross-cultural humility, contextual analysis and awareness, communication skills, stakeholder analysis and engagement, interdisciplinary skills, engineering skills, and leadership and teamwork. Other groups mentioned across respondent types but at a lower rate were systems thinking, design concepts and process, and data collection and analysis. Skills and abilities mentioned but not across respondent types included adaptability and flexibility under changing conditions and contexts, project management, ethics, sustainability, grant writing, and risk analysis and mitigation.

The practitioner response rate regarding missing skills and abilities was too low to allow for analysis. Of the 27 students who responded, the most frequently mentioned groups identified as missing from existing programs were: cross-cultural humility (33%), interdisciplinary skills (26%), and contextual analysis and awareness (19%). These responses helped set expectations for the workshop, inform the workshop agenda and establish a baseline against which to compare the workshop's discussions and outputs.

4.4. Body of knowledge

This section presents the proposed body of knowledge for graduate education in Global Engineering, consisting of 15 learning objectives, their desired level on Bloom's Taxonomy and approaches to achieve this level.

4.5. Learning objectives

Table 4 presents the 15 learning objectives that emerged from the workshop. Writing committee working groups made revisions to the wording of some of these learning objectives after the workshop, but no changes were made to the focus or intent of each objective.

Table 4
Learning objectives for global engineering graduate programs.

Learning objective	Description
Contextual Comprehension and Analysis	Analyze the historical and contemporary context of global inequalities and global development, and poverty alleviation policies, programs, institutions, laws and regulations, and social movements; identify alignments and gaps in (1) research and (2) practice within this context.
Cross-cultural Humility	Recognize and respect cultural differences and apply relevant skills to collaborate across cultures, with an emphasis on life-long learning.
Global Engineering Ethics	Examine ethical implications of global research and development, including consideration of power imbalances; recognize the limitations of engineering in guiding global development efforts.
Stakeholder Analysis and Engagement	Identify project stakeholders and apply appropriate stakeholder communication and consensus building tools.
Complex Systems Analysis	Analyze and be aware of the system of various factors (e.g. technical, sociocultural, environmental, political) and actors (components), including interconnections, trade-offs and feedback within systems that influence the efficacy, equity and sustainability of engineering solutions.
Data Collection and Analysis	Collect and analyze data using both quantitative and qualitative methods, as appropriate.
Data-driven Decision Making	Use methods, tools, instruments and procedures employed in measuring and improving international development projects; discuss commonly used impact evaluation designs and the conditions under which each may be used.
Applied Engineering Knowledge	Apply rigorous engineering practices and principles within a global context and specific local contexts, considering unique constraints and requirements imposed by resource-constrained settings.
Project Design	Identify tools, methods and approaches for project design; design and assess programmatic Theory of Change and evaluation frameworks for global development interventions.
Project Management	Apply project management skills and methods to manage a project from initiation/problem-definition through delivery.
Multidisciplinary Teamwork and Leadership	Function effectively on a diverse team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks and meet objectives.
Communication	Apply and adapt written and oral communication strategies to reach and work with a diverse audience.
Climate Change, Sustainability, and Resilience	Identify and analyze the climate-change dimensions of global inequalities and describe pathways to improved sustainability and resilience, including attention to and approaches at local, regional, national and international levels.
Global Health	Understand principles of global health practice, apply lessons learned from public health interventions and evaluations, and understand how public health influences and evaluates development programs and projects.
Development Economics	Examine historical and current development economics theories and their influence/impact on Global Engineering.

4.6. Bloom's taxonomy

Writing committee members were asked to consider their assigned learning objectives through the lens of Bloom's Taxonomy (Bloom, 1965), wherein they identified whether students of a graduate Global Engineering program should achieve *mastery*, *competence* or *exposure* for a given learning objective, and where:

- *Mastery* is the ability to analyze, synthesize, and evaluate situations; to adapt the response to a given situation in ways that align with the topic and concepts; and to explain the importance of using these methodologies to achieve the desired outcome.
- *Competence* is the ability to apply the concepts and techniques to solve problems differently than provided examples; students' behavior is influenced by the value they place on these topics.
- *Exposure* is the ability to recognize terminology and comprehend the presented concepts; students learn to value these concepts and may achieve a higher level through further study.

Table 5 presents a summary of the consensus within the working groups. In several instances, working groups split a learning objective into two (e.g. quantitative and qualitative data analysis) and proposed different levels for the two. An important limitation to point out is that these working groups consisted of three to five members; therefore, the

Table 5
Bloom's taxonomy of learning objectives for global engineering graduate programs.

Learning objective	Exposure	Competence	Mastery
Contextual Comprehension and Analysis	X		
Cross-cultural Humility		X	
Global Engineering Ethics		X	
Stakeholder Analysis and Engagement		X	
Complex Systems Analysis		X	
Data Collection and Analysis	X	X	
Data-driven Decision Making		X	
Applied Engineering Knowledge			X
Project Design		X	
Project Management		X	
Multidisciplinary Teamwork and Leadership		X	
Communication		X	X
Climate Change, Sustainability, and Resilience		X	
Global Health	X		
Development Economics	X		

consensus in this case was not across the entire writing committee, although all members were invited to review the work of the other groups and propose revisions. Appendix D provides further information on what achieving the desired level would look like with respect to students' knowledge, skills and abilities for each learning objective.

4.7. Proposed approaches

With respect to achieving the priority learning objectives, writing committee members were asked to propose the appropriate format: short courses or workshops; in the classroom; field-based practicum, internship or research; and/or on-the-job training. Within the classroom setting, they were to identify the most useful approach. Active, classroom-based learning techniques are recommended for most learning objectives. These include standard approaches such as readings, classroom-based discussion and debate, and non-standard (to engineering) approaches like role-play simulations and theater in class. For lectures, education's increasingly virtual nature makes it possible to engage guest speakers from around the world. Case studies are recommended across technical and non-technical learning objectives. Written reflections are recommended particularly for non-technical objectives, while lab-based assignments and team projects were recommended for technical ones. Appendix D provides further information on specific approaches for each learning objective.

5. Discussion

The study revealed themes that mirror the evolution of engineering for global poverty reduction and signal the future of Global Engineering. First, there is a need for students to have conventional engineering skills, including applied engineering skills and teamwork. It is no surprise that *Applied Engineering Knowledge* ranked as a top learning objective and important topic for Global Engineering graduate programs across respondent types in the pre-workshop survey. This topic also emerged from the workshop as a priority learning objective, supported by more traditional engineering skills such as Project Design and Project Management, and by other technical skills such as Complex Systems Analysis and Data-driven Decision Making. This signals a clear mandate for graduate programs in Global Engineering to continue to build students' technical depth.

That said, technical rigor is not sufficient to prepare the next generation of Global Engineers. Both curricular and extracurricular activities must integrate anticolonial training too, supporting *Contextual Comprehension and Analysis*. This means teaching engineers that poverty is not an initial stage of inevitable growth to be overcome by conventional technical solutions, but rather that reducing poverty requires accounting for its historical and continuing causes. Such training will prepare engineers to make better-informed decisions and will help the engineering sector move away from emphasizing products and community-level interventions in favor of addressing the root causes of poverty. Without this shift, small-scale programs and products will continue to be ineffective, perpetually undermined by the global economic system's exploitation of low-income communities and unequal distribution of wealth and resources.

Multidisciplinary Teamwork was also a top learning objective, recognized as an important skill across all respondent types in the pre-workshop survey. In the context of Global Engineering, emphasis on multidisciplinary teams goes beyond different types of engineers, given that students will work with practitioners in global health, public policy and other fields. The workshop built *Leadership* into this learning objective with the understanding that good leaders function well on a team even when they are not leading it. There is an important argument for preparing engineers who can work with practitioners from other fields and contribute to solving problems in global health, climate change and other spaces that transcend disciplines: Fundamentally, engineers are problem solvers with important technical skills to offer (Niemeier et al., 2014), but to be effective, they require skills generally absent from traditional engineering curricula. Such interdisciplinary skills received attention in the pre-workshop survey and emerged from the workshop as learning objectives in the form of *Global Health; Development Economics; and Climate Change, Sustainability, and Resilience*. The emphasis was largely on *exposure* to these topics, as opposed to *competence* or *mastery*.

Transversal skills that enable leadership and teamwork across disciplines and contexts and that build on the standard expectations of engineering students were also highlighted. Communication skills were identified as important across respondent types. During the workshop and through the work of the writing committee, it became clear that the *Communication* learning objective needs go beyond standard written and verbal skills to include listening and interpersonal skills. Such skills feed into *Cross-cultural Humility*, which was carried through the workshop as a priority learning objective and a topic of much discussion. Clearly, the next generation of Global Engineers must be equipped to apply their engineering skills with a cultural and contextual awareness neither previously emphasized nor always exhibited by engineers in international development. Building knowledge and skills in *Complex Systems Analysis* can facilitate this too.

To a certain extent, an active classroom setting can build the desired breadth of depth and skills and teach humility, and we lay out specific approaches for the learning objectives to achieve this in Appendix D. At the same time, the need for practical experience in low-resource contexts emerged as important in the pre-workshop survey and as a theme throughout the workshop and the work of the writing committee, with emphasis on developing partnerships with local institutions. Although classroom-based approaches are recommended across many learning objectives, the sense is that achieving *competence* or *mastery* for some learning objectives requires giving students the opportunity to apply what they learned through a practicum, internship, or research experience. Learning through direct experience is a long-established way to engage deeply with subject matter (Kolb, 1984). One of the challenges in studying topics of relevance halfway around the globe is that, to gain a real appreciation for the issues, students must be there in person (Allert et al., 2007). Such opportunities are likely the most critical for students to gain the experience and synthetic thinking that are hallmarks of engineering.

Here, the focus on North American institutions may have created the assumption that most graduate students enrolled in such programs would be from North America and would not have experience in low-resource contexts. This came through in pre-workshop survey responses (e.g. the need for cross-cultural humility and contextual awareness, the lack of practical experience in relevant contexts) and refining of the learning objectives and how to achieve them (e.g. emphasis on practicum or internship experiences and the implication that graduate students would not have this experience). If Global Engineering programs rely on field experience to achieve learning objectives, they must focus on mutual benefit and the principles laid out by the seminal service learning paper (Sigmon, 1979). Otherwise, the field risks perpetuating the practice of prioritizing student privilege, resources and outcomes over the needs of communities being served, which disempowers these communities and promotes neocolonialist practices (Birzer and Hamilton, 2019; VanderSteen et al., 2010).

We recognize the limitations of focusing on 12 to 15 credits as a means to achieve the proposed body of knowledge. This focus is intended to ensure that these priority learning objectives are acknowledged and addressed consistently across graduate programs in North America. To what extent can this network of learning objectives be achieved and by what means? We recommend *competence* as the Bloom's Taxonomy level for most learning objectives, with *mastery* for *Applied Engineering Skills* and *Communication*, and *exposure* for *Contextual Comprehension and Analysis, Global Health*, and *Development Economics*. Such a graduate certificate or core of a graduate program must be supported by the students' backgrounds and experiences, and by the rest of a given program's requirements. In aligning priorities and establishing consensus on this body of knowledge, the goal is not to produce the same Global Engineer across programs, who implements the same solutions across contexts, but to support a new generation of like-minded Global Engineers who approach complex problems in context-specific ways with the requisite skills.

Global Engineers should go beyond the traditional role of engineers—designing and applying technology to address poverty's symptoms—and work with other sectors to address the root causes of poverty. To do so, Global Engineers should prepare to work with varied stakeholders (donors, implementers, service providers, governments and beneficiaries), participate in policy-making from the early stages of the policy cycle, and solve engineering and science problems within the constraints often encountered in low-resource settings. Evidence-based policy making increasingly aims to enhance impact and accountability in global development interventions by establishing links between monitoring and evaluation, policy formulation, and budget allocation (Gertler et al., 2016). The Royal Academy of Engineering points to the need for engineers' involvement in policy making and recommends their participation from the beginning of the policy cycle. This will provide more and better information to governments, and allow engineers to better understand the context in which they approach challenges (Ettridge and Sharma, 2020).

Improving policies and practice does not preclude the field of Global Engineering from also engaging in innovation and technology design. In fact, technological innovation can and should support public policy, knowledge generation and public participation in addressing the causes of poverty. The above body of knowledge equips Global Engineers to take an active role across these approaches to improve global development and equity.

6. Conclusion and future work

In this paper, and in Appendix D more specifically, we have proposed a set of 15 priority learning objectives and approaches to achieving them that we believe answers the question: *What is the graduate level body of knowledge in Global Engineering that can equip students with the context, skills and attitudes to practice global development equitably and systemically?* Technical skills remain central to preparing the next generation of Global Engineers and make up an important subset of the learning objectives. Transversal and interdisciplinary skills are equally important, however, in equipping students to work across sectors and to account for structural and systemic barriers to global poverty reduction when designing and implementing technical interventions.

This consensus body of knowledge builds upon prior work by the workshop convening organizations. It is the result of input from workshop participants from 38 North American academic institutions and 17 organizations engaged in Global Engineering followed by work by the 22-person writing committee made up of 13 faculty, two practitioners and seven students. Relying on this diverse set of stakeholders and an iterative, participatory process was intended to build consensus on the resulting body of knowledge. We recognize that there were limitations in engagement and input as work progressed on specific learning objectives in the smaller working groups within the writing committee. The next step to broaden engagement and input will be to re-convene all workshop participants for Part 2 of this workshop series, where we will share the body of knowledge for discussion and will solicit input on its implementation across programs. We will also work to engage external stakeholders, with an emphasis on practitioners, through the network of participants and the convening organizations' broader networks, for example ASME's Engineering for Global Development (EGD) group and MCGE's Advisory Board and alumni.

Although this work has focused on graduate education in North America thus far, the Global Engineering academic community of practice is much broader, and there are opportunities to expand this discussion and engagement to undergraduate educators, global academic institutions, and those undertaking Global Engineering research. The continued participation of practitioners in the conversation will remain central to ensuring the body of knowledge is grounded in reality and both informs and is informed by current practice. ASME's EGD Stakeholder Summit 2022: Engineering Workforce Driving Sustainable Development represents one specific opportunity that will bring together a broader set of stakeholders to move the discussion forward on how to equip the next generation of Global Engineers.

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Declaration of competing interest

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Appendix A. Participating Institutions

Institution	Type
American Society of Mechanical Engineers	Practitioner
Berkeley Air Monitoring Group	Practitioner
Bill & Melinda Gates Foundation	Practitioner
Bridges to Prosperity	Practitioner
Centers for Disease Control and Prevention	Practitioner
Conservation X Labs	Practitioner
DAI	Practitioner
Engineering for Change	Practitioner
Engineers in Action	Practitioner
Engineers Without Borders-USA	Practitioner
Lemelson Foundation	Practitioner
Millennium Water Alliance	Practitioner
National Science Foundation	Practitioner
Stantec, Inc.	Practitioner
Tetra Tech, Inc.	Practitioner
USAID	Practitioner
Water for People	Practitioner
Arizona State University	University
Brigham Young University	University
California Polytechnic State University	University
Carnegie Mellon University	University
Clemson University	University
Colorado School of Mines	University
Colorado State University	University
Cornell University	University
University of Colorado Boulder	University
Drexel University	University
Duke University	University
Emory University	University
Fort Lewis College	University
George Fox University	University
Iowa State University	University
Massachusetts Institute of Technology	University
Michigan State University	University
Michigan Technological University	University
Ohio State University	University
Oregon State University	University
Pennsylvania State University	University
Purdue University	University
Regis University	University
Texas A&M University	University
Tufts University	University
University of California, Berkeley	University
University of Massachusetts	University
University of Michigan	University
University of Minnesota	University
University of Missouri	University
University of North Carolina at Chapel Hill	University
University of Rhode Island	University
University of South Florida	University
University of Texas at Austin	University
University of Toronto	University
University of Virginia	University
University of Washington	University
Villanova University	University

Appendix B. Graduate Program Presentations

Colorado School of Mines

The Colorado School of Mines (CSM) Humanitarian Engineering and Science (HES) program defines Humanitarian Engineering as by "harnessing the power of engineering and social science, we work directly with communities to jointly define problems and create sustainable solutions." CSM established its undergraduate humanitarian engineering program in 2003, but its graduate-level offerings were developed more recently. As of Fall 2020, HES now offers an online graduate certificate and, both, thesis and non-thesis Master of Science degrees. CSM's Masters programs consist of 15 credits of HES core courses, including either research credits (thesis) or practicum credits (non-thesis), and 15 credits in one of three disciplinary tracks: geophysics, environmental engineering, or geological engineering. The program teaches students to understand problems in their social context, ask the right questions, listen contextually and co-design with the people they seek to serve. Practical applications and experiential learning are provided through project-based learning in classroom-based courses and through the practicum or thesis research, which includes research translation for non-academic audiences.

Massachusetts Institute of Technology

Although there are no formal degree programs in Global Engineering at the Massachusetts Institute of Technology (MIT), the university has several entities involved in Global Engineering research, collaboration, and education. The Global Engineering and Research (GEAR) Lab "characterizes the unique technical and socioeconomic constraints of emerging markets, then combines these insights with engineering science and product design to create high-performance, low-cost, globally-relevant technologies." The GEAR Lab supports PhD and Masters student research in global engineering, and Director Amos Winter teaches a graduate-level mechanical design class on Global Engineering each year. MIT's D-Lab emphasizes including local communities in innovation to develop practical solutions to global poverty challenges. Most courses offered through the D-Lab are undergraduate. The Abdul-Latif Jameel Water and Food Systems Lab supports research through seed grants, technology transfer grants, and student fellowships. Although not currently active due to discontinued funding, the Tata Center was a catalyst for change with respect to MIT's approach to technical research for global development.

University of California, Berkeley

The University of California, Berkeley's graduate programs in Development Engineering are housed in the Blum Center for Developing Economies. They define Development Engineering as "a field of research and practice that combines the principles of engineering with economics, entrepreneurship, design, business, natural resources and social science to create technology interventions in accordance with and for individuals living in low-resource settings." Berkeley offers two graduate-level programs in development engineering: (1) a designated emphasis for doctoral students from any department whose dissertation research is related to development engineering, and (2) a Master of Development Engineering. Both apply human-centered design methodology and emphasize co-design with community partners. The emphasis consists of two core courses and three electives. The Masters launched in Fall 2021 as a three-semester program with a summer internship. The program curriculum is T-shaped, with breadth of knowledge achieved through courses on ethics, data analysis, social entrepreneurship, communication, design thinking, systems thinking, and critical thinking. Depth is achieved through a concentration in either sustainable design, healthcare, artificial intelligence and data analytics, or energy, water and environment, or a self-designed option.

University of South Florida

The University of South Florida (USF) Engineering for International Development Program offers a graduate degree concentration for Masters and PhD students that integrates traditional engineering, and humanitarian and development coursework with an international engineering experience in a low- or middle-income country focused on addressing multiple Sustainable Development Goals. The program emphasizes "global competency", defined as the "ability to understand and work effectively with engineers and other co-workers who are raised, educated and living in countries other than their own and who solve and define problems differently than oneself." Required coursework covers water, sanitation, and hygiene engineering, as well as global health, and anthropology. Students are also required to engage in full-time global training and service as part of the concentration, and there is a research thesis/dissertation requirement. USF also offers a different pathway for Returned Peace Corps Volunteers and other students who have obtained international experience before attending USF.

University of Colorado Boulder

The Mortenson Center in Global Engineering (MCGE) at the University of Colorado Boulder trains engineers to work in partnership with institutions and communities worldwide to develop improved tools and methods to address global challenges. Its education program is based on the principle that students educated in Global Engineering will be prepared to solve engineering and science problems within the socioeconomic, environmental, and political constraints often encountered in lower-resource settings. At the graduate level, MCGE offers a Graduate Certificate in Global Engineering, a Professional Master in Global Engineering, and a Professional Master in Global Environmental Engineering. All three have the same core requirements: a course on global development for engineers and a field-based global development practicum, during which students are embedded with a global development organization for two to three months. The Professional Master in Global Engineering is designed to expose students to a breadth of knowledge in areas such as global health, development economics, and impact evaluation, while also building technical skills and providing the opportunity for further study in a specific area of interest within global engineering.

Appendix C. Workshop Agenda

NSF GE Pedagogy Workshop, Part 1
February 18–19, 2021, 9am–11 am MT

Day 1
What is global engineering? What do global engineers need to know and know how to do?

Time	Topic	Pre-reading/viewing
8:45–9:00am	**Registration** - Log on and familiarize yourself with the platform; say hi to other participants in the Networking Lounge	
9:00–9:05am	**Welcome** by Associate Dean Doug Smith of the CU Boulder College of Engineering and Applied Science.	**Plenary Talk by Evan Thomas** (pre-recorded): What is Global Engineering? What is the role of global engineering in contributing to global poverty reduction?
9:05–9:10am	**Workshop Introduction** by Karl Rockne Program Director of the Environmental Engineering Program at NSF	
9:10–9:15am	**Organizers' presentation**: Overview of workshop aims, schedule and platform	
9:15–9:40am	**Lightning Talks:** Global Engineering in higher education *Objective:* Introduce participants to examples of existing programs and their approach to educating the next generation of global engineers. *Logistics:* 4 × 5 min talks by representatives from existing university programs, with transition time in between.	**Landscape of Existing Programs** summarizing program responses to BOK surveys, with supporting documents such as syllabi, brochures
9:40–9:55am	**Panel Q&A** with Plenary and Lightning Talk Speakers	
9:55–10:05am	**Bathroom & Coffee Break**	
10:05–10:35am	**Breakout 1**: Proposed learning objectives *Objective:* Based on participant experience and the opportunities and challenges laid out in Plenary Talk 1, outline the learning objectives that should make up the graduate-level Global Engineering body of knowledge.	**Summary of Survey Responses** from participants; **Introduction to Bloom's Taxonomy**

(*continued on next page*)

Day 1 (*continued*)

Time	Topic	Pre-reading/viewing
	The expected outcome of this session is a proposed list of learning objectives to be prioritized and then mapped in Breakout 2. *Logistics:* The discussion will take place in breakout rooms. Each breakout room will have one facilitator and one graduate student assistant. Breakout rooms will be divided into faculty, graduate student and practitioner tracks.	
10:35–10:55	**Report back from Breakout 1**	
10:55–11:00am	**Closing**	Organizers will synthesize the lists from Breakout 1 into a common list of priority learning objectives; summarize other key takeaways from the breakouts.
11:00am-12:00pm	**Optional: Networking Lounge**	

Day 2
How do we achieve this?

Time	Topic	Pre-reading/viewing/homework
9:00–9:10am	**Welcome** and **Day 1 Key Takeaways**	
9:10–9:25am	**Q&A** with Jack Colford	**Fireside Chat with Jack Colford** (pre-recorded): How do academic institutions prepare students to be practitioners in an emerging field?
9:25–10:10am	**Breakout 2: How to achieve the learning objectives** *Objective:* Discuss approaches to achieving priority learning objectives (courses, practicum/internships, online offerings, etc.) *Logistics:* The discussion will take place in breakout rooms, as previously assigned for Breakout 1.	
10:10–10:20am	**Bathroom & Coffee Break**	
10:20–10:50am	**Report back from Breakout 2**	
10:50–11:00am	**Workshop Closing and Next Steps**	
11:00am-12:00pm	**Optional: Networking Lounge**	

Appendix D. Body of Knowledge

Contextual Comprehension and Analysis

Description

Global Engineering students should be equipped to: ***(1) analyze the historical and contemporary context of global inequalities and global development, as well as poverty alleviation policies, programs, institutions, laws and regulations, and social movements; and (2) identify alignments and gaps in research and practice within this context.*** It is imperative that Global Engineering students interested in working within the global development context study historical and socioeconomic factors impacting global development. In order to minimize and discontinue unjust, inequitable practices, policies, and programs in the context of global development, Global Engineering students must critically analyze historical and contemporary approaches to development and recognize the impacts that Global Engineering can have in perpetuating or ending historical systems of oppression and inequality.

Motivation and Background

Evidence shows that the diversity found in worldwide patterns of global development, poverty, wealth, and human well-being has roots in the actions and injustices of past societies. A range of adverse outcomes is attributable to both historical and contemporary approaches to development. Colonialism and the transatlantic slave trade created mass human suffering across much of the world, caused poverty in colonized societies, and left countries with economic structures that, to this day, make development difficult, if not impossible.

European settlers positioned themselves as superior to those they conquered and exhibited a sentiment of superiority and exceptionalism that continues in 21st-Century development practice. Furthermore, imperialist and settler colonization ideologies led to interference in regime changes in various parts of the world. Through structural adjustment, large, multinational financial institutions have enforced unjust debt collection and trade deals that exacerbated inequalities (Hickel, 2018). Misguided contemporary programs and policies have, *inter alia*, created dependency on the people or resources deployed in an intervention, endowed practitioners and academics with the power to establish such interventions, and treated the beneficiaries of interventions as disposable (Rutazibwa, 2019).

Bloom's Taxonomy

In a graduate certificate, we would expect students to achieve *exposure* in Contextual Comprehension and Analysis. To mitigate adverse impacts of development programs, policies, and interventions, it is essential that Global Engineering students understand the context in which they work. Students must acknowledge and analyze the colonial history that shapes international development, identify colonial legacies and historical exploitation in global engineering, individual mindsets and behaviors (including their own), and discuss decolonization in the places students live, study, and work. Students should be able to explain the history of international development agencies – how and why they formed and what functions they intend to serve – and to develop and defend a normative argument about different approaches to international aid and development.

Additionally, students should be encouraged to challenge the status quo and to understand and question the foundations of racism, colonization, and imperialism that result in generational inequalities. Besides the global historical perspective, this learning objective works in concert with stakeholder engagement and analysis, equipping students to understand the local socio-political past and present, the systems into which their work must fit, the key institutions and actors with which they will interact, and the relationships that they are trying to build.

Given the varied extent to which these historical and contemporary inequalities are discussed in North American global engineering programs, this learning objective can be seen as divergent. In the pre-workshop survey, representatives from ten participating institutions with graduate programs in Global Engineering were asked: *Does the program include a critical discussion of the history of international development?* The depth of responses to this question varied: some programs outlined a course for the historical and contemporary impacts of international development, others incorporated the topic into a seminar class or extracurricular discussion series, and many acknowledged that it is an ongoing discussion and work-in-progress. The topic's importance emerged from the pre-workshop survey, which asked individual participants (students, faculty, and practitioners): *What, do you believe, are the most important skills/abilities that graduate students need to work within the global development sector?* Clearly, Global Engineering programs need to work together to further a structured approach to this learning objective and ensure that it is woven throughout a program rather than in side discussion.

Approach

We recommend that Contextual Comprehension and Analysis be woven throughout the global engineering curriculum. Beyond this, a mandatory course or seminar series that explicitly addresses this learning objective should be included in the curriculum to ensure that all students of a Global Engineering program are aware of the systems that foster inequalities. The skills of challenging existing injustices can also be sharpened through field-based practicum or internship.

Cross-cultural Humility

Description

Global Engineering students should be equipped to ***recognize and respect cultural differences and apply skills to collaborate across cultures, with an emphasis on life-long learning.*** In seeking to learn about a culture, students should recognize the value of knowing as much as possible about the community and context in which they work, albeit with the humility of understanding that they will never achieve cultural *competence*, or "a detached mastery of a finite body of knowledge" (Tervalon and Murray-García, 1998). Unlike competence, humility is not a discrete endpoint, but a commitment to active learning throughout one's life and career, and a practice that must be carried out on an ongoing basis with oneself, with one's colleagues and other individuals, and with communities (Tervalon and Murray-García, 1998).

Motivation and Background

In work to support global poverty reduction, the inherent assumption by Global Engineers is that they have the tools, knowledge, and/or skills to improve the well-being of underserved and vulnerable populations in resource-limited settings. The role of Global Engineering graduate programs is to ensure that students are, in fact, equipped to solve "wicked problems" (Andersson and Törnberg, 2018) and not contribute to the "White Savior Industrial Complex" (Cole, 2012) common throughout international development. Countering this complex requires respect for the agency of a population, and for the work already done and that continues to be done by this population, regardless of external intervention (Cole, 2012). Cross-cultural Humility supports students to consider and counteract power imbalances in the relationship between local stakeholders and external actors (Tervalon and Murray-García, 1998), aided by competency in Contextual Comprehension and Analysis and Stakeholder Analysis and Engagement.

Bloom's Taxonomy

Given that building Cross-cultural Humility is a life-long process, we recommend that students achieve *competence* through a graduate program, ensuring that they can apply what they learn and value Cross-cultural Humility to the extent that it will continue to influence their behavior. As a learning objective, Cross-cultural Humility relies on and contributes to the objectives of Contextual Comprehension and Analysis, Communication, and Stakeholder Engagement and Analysis. Students must understand cultural identity, engage in intercultural communication, gain cultural knowledge, and open themselves to cognitive flexibility. Self-awareness, and understanding of one's own culture and implicit biases should be established through self-reflection and self-critique (Tervalon and Murray-García, 1998). Prior to engaging with other cultures, students should spend time practicing cultural awareness and learning about the context and stakeholders impacting their work. These skills are critical regardless of whether students intend to travel for a program or project, or engage in the work remotely.

Approach

Although a classroom setting alone cannot achieve competence with respect to Cross-cultural Humility, active learning techniques can introduce this concept and initiate the life-long learning process, with subsequent field experience building knowledge and skills. For example, students can complete the Intercultural Development Inventory to measure their orientation toward cultural differences (Hammer et al., 2003), or Harvard's Implicit Association Tests to identify and understand the implicit attitudes and beliefs that they hold ("Project Implicit Overview," 2011). Written assignments can further explore their biases and reflect on their self-awareness, awareness of others and other cultures, and flexibility. Readings and classroom discussions of religions, political groups, and cultures can arrive at a term project where students research a country's history, political structure, languages, religions, and other cultural practices. Through field experience, students could apply and further develop classroom-acquired knowledge and skills, building deeper understanding of the specific context while strengthening cross-cultural skills that facilitate life-long learning.

Global Engineering Ethics

Description

To ensure that Global Engineering impacts society positively, ethical considerations must inform research and practice. Global Engineering students will learn how to ***examine the ethical implications of global research and development, including consideration of power imbalances, and recognize the limitations of engineering in guiding global development efforts.*** Through this examination, they will identify and discuss how to address ethical challenges in global development contexts, including power imbalances, existing inequities, systemic injustices, and unintended consequences. Students will be able to identify the ethical issues that can exist throughout the lifecycle of a global engineering project – from idea and proposal development, to data collection and analysis, to dissemination and impact – including the ethical challenges of emerging engineering solutions like artificial intelligence.

Motivation and Background

While Global Engineers strive to support ideals such as social and distributive justice, environmental sustainability and protection, gender equity, human rights, and peace, many development projects inadvertently reinforce norms or injustices that work against these ideals. To minimize unintended consequences of engineering design and implementation, students must develop an ethical framework that enables them to recognize and examine the ethical implications of global research and development, and select pathways that promote ethical and equitable outcomes for all stakeholders.

Adopting an ethical framework requires introspection and critical reflection on students' own ethical theories and traditions, and examination of theoretical perspectives that lead to different ethical commitments and concepts of service. Students must learn to use technical, social, and economic criteria to evaluate how, when, and whether engineering alternatives are beneficial to the well-being of all members of society.

Bloom's Taxonomy

We propose that students in a Global Engineering graduate certificate program achieve *competence* in their understanding and application of Global Engineering Ethics. Students should be able to describe and discuss major ethical challenges in the fields of international development and Global Engineering from an interdisciplinary perspective. They should be able to explain theoretical and applied ethical debates, and moral puzzles and challenges with respect to ethics in international development. When considering a specific situation, Global Engineering students should be able to identify how, when, and whether engineering solutions are beneficial, and to defend technically and ethically just engineering alternatives.

Approach

These concepts are best explored in the classroom, in small, in-person groups conducive to open conversation and self-reflection. Here, we present suggestions for teaching different components of the course. Case studies can provide students the opportunity to identify and evaluate ethical implications of historical engineering and international development projects. Case studies can also ask students to connect theoretical and conceptual knowledge in real-life ethical challenges, and present a personal analysis of an ethical dilemma.

In role-play simulations, students assume stakeholder roles in a scenario. In discussion afterward they to learn to differentiate ethical implications for all relevant stakeholders, examine their decisions and actions, and reflect on how these may be based on their own biases and experiences. Self-reflection exercises can help students clarify their own ethics and the basis for them, such as a written assignment on ethical topics (e.g., proselytizing), or an exercise where students place themselves in groups based on agreement with a statement (e.g., "Poverty will always be with us") and make a case for their position. Theater in class (e.g., "theater of the oppressed") is another tool, during which students write and perform a three-minute script on a social justice topic and discuss the performances as a group.

These example activities could also be used to build students' ability to construct sustained normative arguments on different global issues, such as humanitarian assistance, immigration, war and peace, and climate change and be able to defend them against opposing arguments and perspectives.

Stakeholder Analysis and Engagement

Description

Global Engineering students should be able to ***identify project stakeholders and apply appropriate stakeholder communication and consensus-building tools.*** A key aspect of Global Engineering is identifying local stakeholders for inclusion in the project and evaluating societal needs. Thus, students must be highly competent in the tools and best practices for stakeholder identification and engagement to enable productive collaboration, co-design and decision making that equitably and sustainably impact all stakeholders. Students must be able to "engage in the complexities of a negotiated design process occurring between multiple stakeholders in a professional and ethical manner, and demonstrate empathy and adaptability in working with teammates and stakeholders with varied skills, talents, abilities, and work strategies" (Payne and Jesiek, 2018).

Motivation and Background

Stakeholder Analysis and Engagement requires understanding the social justice dimension of global development, knowing who benefits (or loses out) as a result of a development intervention, and including stakeholders in the project (Smith, 2019). Indeed, Honadle and Kennealy (Honadle and Kennealy, 2011) state that "stakeholder participation in community planning is essential to effective planning practice." Among other benefits, the meaningful involvement of stakeholders fosters the democratic process, ensures that plans address community needs, and improves the likelihood that plans will be accepted by the community. It is important to go beyond empathizing with stakeholders and involve them in the design process (Leydens and Lucena, 2009; Mattson and Wood, 2014; Mazzurco and Daniel, 2020; Mazzurco and Jesiek, 2014).

Thus, Global Engineering education must teach techniques for stakeholder identification and engagement, and analysis of input from stakeholders, fundamental to the preparation of planners who can develop holistic solutions to complex development challenges.

Bloom's Taxonomy

We recommend that students in a Global Engineering graduate certificate or equivalent reach *competence* in Stakeholder Analysis and Engagement. To achieve competence, students must have strong and adaptive understanding to apply best practices and techniques of stakeholder identification and participatory engagement. This understanding must be supported by a range of theory and practice within both engineering and social sciences. Students should be familiar with techniques of stakeholder identification and analysis, and collaborative approaches such as collective action. They should also know methods such as systems modelling to collect and analyze input from stakeholders to prioritize needed actions, or such as network analysis to map the involvement and coordination of stakeholders (Harper, 2020). Participatory systems modeling involves local stakeholders in mapping and assessing factors that influence engineering services to find leverage for impactful policy and practice (Hovmand, 2014; "Systems

Practice," 2017; University of Colorado Boulder, 2019; Valcourt et al., 2019; Vennix, 1996; Walters et al., 2017). Ika and Donnelly (Ika and Donnelly, 2017) highlight multiple stakeholder engagement to avoid failed projects that didn't account for local needs. To reinforce this, students should be made aware of lessons from reports about past failures caused by inadequate needs assessment.

Approach

Exposure and initial steps toward competence in Stakeholder Analysis and Engagement can be achieved in the classroom through a combination of activities. We recommend readings and classroom discussion about the failures of projects from improper needs assessments and stakeholder engagement, paired with best-practices (guest) lectures by social scientists, community engagement experts (e.g., local or regional coordinators), and community/urban development professionals or researchers in urban studies.

Techniques to highlight in such lectures include: participatory action research (Chambers, 1994); human-centered design (e.g., IDEO) and co-design (e.g., MIT D-Lab) (Eseonu and Cortes, 2018); cultural awareness and cross-cultural communication training; engineering for social justice (Lucena, 2013; Riley, 2008); social network analysis (Harper, 2020; LINC, 2021; McNicholl, 2017; Sommerville et al., 2015) and stakeholder mapping to identify key stakeholders or knowledge gaps (Rowley, 1997); and participatory mapping. Stakeholder simulations and role-playing provide a classroom-based opportunity to build on techniques covered in lectures and discussion by having students assume different roles, then reflect on and discuss the experience (Alaswad and Salman, 2020; Coll-García, 2020). The ability of students to apply techniques through classroom-based activities will differ between those that emphasize stakeholder identification and analysis (e.g., social network analysis, stakeholder mapping) and those intended to be participatory and engage stakeholders (e.g. participatory rural appraisal), best practiced in active projects.

Toward that end, we recommend that students continue building competence by applying these skills in a field-based practicum, internship, or research. Depending on the context and scope of work and the student's role in it, we recognize that not all experiences will include the opportunity to participate fully in stakeholder analysis and engagement but there will be elements that can be considered and applied. When appropriate, we recommend conducting focus group discussions on participatory problem identification and co-design of solutions (Emergency Capacity Building Project, 2007; Koscalova, 2012). Semi-structured interviews with community partners stimulate conversation and allow for a deeper dive into specific topics with key informants.

Complex Systems Analysis

Description

Complex Systems Analysis, thinking and modeling ***analyzes the factors (e.g., technical, sociocultural, environmental, political) and stakeholders (e.g., government officials, consumers, community members) – including their interconnections, trade-offs, and feedback – in systems that influence the efficacy, equity, and sustainability of engineering solutions.*** Unmet needs (e.g., food, energy, water, health, shelter) in a community often result from complex systems of social, economic, and environmental components that are temporally and spatially dynamic (Lönngren and Svanström, 2016). Technological solutions are not implemented in isolation; their use and effectiveness rely on a structure that promotes sustainable, effective, and equitable delivery of services (Amadei, 2015; Bossel, 2007; Holtz, 2011; Ramalingam et al., 2014). And it is critical that Global Engineering students have an actionable paradigm and toolkit to navigate the interconnected challenges they will encounter.

Motivation and Background

The most pressing societal challenges present uncertainty from dynamic, interdependent systems(Andersson and Törnberg, 2018; Hess et al., 2014; Lönngren and Svanström, 2016; Mensah et al., 2018). Because of rapid change within these, it is difficult to predict outcomes and rule out error. Understanding the interaction of actors and feedback mechanisms in complex systems can avoid engineering solutions with low effectiveness, failure, or unforeseen negative consequences in the community (Yang and Cormican, 2021). Systems thinking, and modeling tools and techniques can support decision making by considering interactions and feedback. This allows engineers and practitioners to make holistic design decisions that maximize synergies and minimize tradeoffs (Rehmann et al., 2011).

This need is not confined to Global Engineering. The learning outcome is highlighted by ABET Learning Outcome 3-1: "an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics" (ABET, 2018). But current pedagogical research and practice in systems thinking and modeling tend to be overly complex, difficult to implement in an engineering curriculum, and inaccessible to local stakeholders. Thus systems thinking and modeling technique must: (1) be accessible both to practitioners (universities, engineering firms) and local stakeholders (faith-based organizations, NGOs, women's organizations, aid agencies); (2) engage local stakeholders (who are experts in their system context); (3) offer actionable insights on where to intervene in the system with policy and practice; and (4) provide these insight through a lens that considers interconnections, dynamics (i.e., feedback), and adaptation or mitigation strategies for unforeseen changes.

Bloom's Taxonomy

We recommend that graduate students in Global Engineering achieve a high level of *competence* in Complex Systems Analysis through participatory systems thinking and modeling tools. The participatory aspect implies that stakeholders are engaged throughout the process of systems modeling, reflection on model outputs, and co-design of engineering and management solutions. This requires students to be familiar with the best practice principles, methodologies, models, tools, and techniques to analyze complex systems with local project stakeholders. These range from qualitative systems modeling techniques (such as soft systems analysis (Moffatt and Hanley, 2001) and causal loop diagramming (Neely and Walters, 2016; Richardson, 2011)) to semiquantitative and quantitative techniques in building a system dynamics model, structural factor analysis (Godet, 1994), and network analysis (Chinowsky et al., 2008; Larson et al., 2013; Scott, 2000) to develop stakeholder knowledge of complexity. Students should be able to engage stakeholders in identifying interconnected social, economic, and environmental design constraints, key actors in the local system, and temporal-spatial dynamics that enable or inhibit project or program success. Students should learn tools, techniques, and best practices in stakeholder engagement and workshop facilitation to enable multi-stakeholder discussion of model outputs that address nuanced conflicts, synergies and trade-offs across competing requirements of the local context.

Approach

We recommend a flipped classroom and project-based approach that relies on lectures, active learning, and discussions and interdisciplinary team projects to build students' competence in systems thinking and modeling of complex socio-technical systems. These should incorporate Stakeholder Analysis and Engagement, critical to understanding complex systems and working with stakeholders to achieve systemic change. Lectures should cover systems thinking paradigms such as complexity, interconnectedness, chaos, emergence, endogenous drivers, etc. (Mitchell, 2009) Lectures should also cover tenets and best practices – such as approaches in participatory factor and actor modeling highlighted in the Sustainable WASH Systems Learning Partnership – to teach the complex interaction of factors that drive system outcomes. These could include factor mapping (Hovmand, 2014; Valcourt et al., 2020; Vennix, 1996; Walters et al., 2017) , and social/organizational network analysis(Harper, 2020; LINC, 2021; McNicholl et al., 2017; McNicholl, 2017; Sommerville et al., 2015). Case studies and written assignments can allow students to apply theoretical concepts and frameworks covered in lectures. These would build toward a term project in which students develop their own case study, analyze and define the system in which an intervention is being implemented, and recommend ways to improve the approach. Ideally, the case study would be developed in collaboration with an organization or community that already identified an issue and can be supported in addressing it through stakeholder engagement and complex systems analysis. A process of refinement and iteration where students provide peer review would bolster model development.

The depth and level of engagement of students can be applied within two complimentary tiers:

Tier 1 - Entry Level: Integration of modules into design courses in which students use system thinking tools such as pairwise comparison tables, causal loop diagramming, decision matrices, and others to address traditional and global engineering challenges. This might require increasing diversity of case studies, project-based learning, discussing ways to engage with stakeholders to identify factors, and their pairwise interactions.

Tier 2 - More Advanced: Systems analysis, thinking, and modeling courses that cover in-depth topics such as system dynamics modeling and simulation, and network analysis, among others, followed by a project-based course where students interact with stakeholders and apply system thinking to model engineering solutions. Students should also engage in peer review and third-party review of complex systems thinking and modeling.

Data Collection and Analysis

Description

This learning objective focuses on how ***to collect and analyze data using quantitative and qualitative methods.*** Various forms of data collection and analysis are critical for answering questions in the field of Global Engineering. Data can give numerical insight, additional context, or both to the challenge at hand. Global Engineers need to effectively and appropriately collect, analyze, and interpret data to ensure sound methodological and scientific contributions. Regardless of the topic of interest, methodological approaches should be selected carefully and utilized to ensure meaningful application.

Motivation and Background

Global Engineering relies on an intersection of mixed-methods approaches that bridge quantitative information (i.e. more traditional engineering) and qualitative context (i.e. social and behavioral sciences) (Borrego et al., 2009; Sovacool et al., 2018). Quantitative data collection may include sensor-based data collection, the use of survey software (Anokwa et al., 2009; Harris et al., 2009), and/or mobile data collection(Akhmetov and Aitimov, 2015; Sharma and Gupta, 2014). Meanwhile, interviews, focus groups, and observations are qualitative methods that provide context and a better understanding of why a phenomenon occurs (Patton, 2001). Qualitative data provide nuance and deeper understanding, while quantitative data coupled with statistical analysis give insight into outcomes across a sample population (Driscoll et al., 2007). Different methods will be optimal in different situations and these should be considered prior to any data collection.

Planning for data validation and analysis before initiating data collection ensures that the data can be analyzed and answer the research question. Quantitative data validation (also called data cleaning) can include randomly sub-setting data to look for correct skip patterns, recoding categorical or numerical data, and creating dummy variables for downstream analysis. Similarly, qualitative data requires data coding (also called indexing) to categorize ideas, concepts, phrases, and behaviors. Quantitative analyses can include descriptive statistics and/or further inferential analyses, such as correlation tests, regression models, and analysis of variance tests. Qualitative analyses identify patterns and connections, and they use content, narrative, and discourse analyses and grounded theory. Data visualization tools help present and interpret both quantitative and qualitative approaches (Perkel, 2018).

Both data collection and analysis should emphasize data quality. An aspect of good data quality is implementing quality control and assurance processes during collection. For example, double data entry (Barchard and Pace, 2011)or electronic data entry (Harris et al., 2009)and frequent data downloads to check data quality are important. Understanding the timeline associated with each step – data collection, cleaning, and analysis – can help plan execution of deliverables.

Mixed methodologies support students as critical thinkers and problem solvers. From a quantitative perspective, a Global Engineer should practice developing survey instruments to minimize bias and maximize relevance. Sample size requirements to obtain statistical power and confidence measures are also necessary knowledge. From a qualitative methods perspective, a Global Engineer should have exposure conducting or shadowing in-depth interviews and focus group discussions, when appropriate.

Bloom's Taxonomy

We recommend that students achieve *competence* in either quantitative or qualitative methods, and have at least *exposure* to the other. Students should be familiar with the main sources of secondary data and be able to identify, analyze, and evaluate secondary data. They should be exposed to the most common qualitative and quantitative data collection methods, tools, and instrumentation, and should be able to develop and deploy a basic survey instrument and follow standard test procedures. Students should be able to employ analytical tools to illustrate and discuss the utility and impact of solutions for pressing topics such as access to water resources, agriculture, disaster forecasting and relief, air quality, and global health.

General engineering education emphasizes quantitative skills, so it would be reasonable to expect Global Engineers to need qualitative methods. Realistically, while learning both quantitative and qualitative skills is worthwhile, work environments will lead students to choose one or the other.

Approach

The quantitative methods for a beginning Global Engineer are best learned in a classroom setting with lab-based assignments through biostatistics or statistics classes. Additional specialization can be done through epidemiology coursework. Most engineers likely would not have exposure to public health courses prior to graduate school, and enrollment in such courses would build data collection and analysis skills and provide exposure to public health concepts and approaches.

Data visualization skills can be learned through short courses, LinkedIn Learning, Stacks Exchange, or online resources for R, RStudio, Python, or other software programming languages. Qualitative methods can be taught through a classroom setting and exercised through a final project, research project, or activity-based learning(Fallon et al., 2012; Janakiraman et al., 2021). Mastery of quantitative and/or qualitative methods can be achieved through thesis/dissertation research and/or on-the-job application.

Data-driven Decision Making

Description

Global Engineering students should be able to ***use methods, tools, instruments, and procedures employed in evaluating and improving development interventions.*** This includes discussing common impact evaluation designs and conditions under which each may be used, and designing methods for impact evaluation and performance monitoring. It is important to be familiar with the Theory of Change and indicators used to measure progress towards an intervention's achievement, considering both technical and institutional dimensions. To increase accountability and improve performance, it is key to generate data that is actionable, timely, and delivered as interpretable information so stakeholders can assess impact and improve strategies and policies. Finally, it is important to identify ethical issues when conducting impact evaluations, understand power dynamics related to impact measurement and decision making, and criticize colonial and otherwise unjust practices.

Motivation and Background

Political focus on the effectiveness and accountability of development programs has grown in recent decades by basing programming on evidence, increasing evaluation, and strengthening its rigor (Jones, 2012). However, previous efforts to improve evidence-based decision making failed because they used frameworks from other fields rather than address the complex challenges faced by development actors (Jones, 2011). While donors increasingly support the use of evidence in decision making, this focuses on narrow issues instead of promoting its systematic use. There is a lack of coordination between funding organizations in evidence production, and a lack of definitions to measure the impact of activities related to data-driven decision making (Taddese and Gandolfo, 2018).

However, emerging methods, approaches, and technologies to monitor impact can increase accountability and effectiveness in the humanitarian and global development sector. Feedback is needed to drive change as approaches are refined and programs adapt to context, and for institutional behavior change among donors and governments who fund and implement programs (Thomas and Brown, 2021). Global Engineers should play a role in this process and fill the gap between policy makers, researchers, implementers, and beneficiaries of global development interventions.

Furthermore, engineers should participate in early stages of the policy cycle to develop solutions with broader understanding of the challenges and inform governments' perspectives (Ettridge and Sharma, 2020). To participate in public policy, engineers should acquire an understanding of the workings of government and policy making, the ability to communicate beyond disciplinary boundaries and weigh technical and non-technical issues in decisions, and an understanding of the diverse interactions of technology and society (Mendoza-Garcia et al., 2012).

Bloom's Taxonomy

According to Bloom's Taxonomy definition of different levels of training, graduate students in Global Engineering should reach *competence* in data driven decision making. This will allow them to go beyond mere understanding of tools and methods to define the best study design for each context, and to translate the data into evidence-based solutions and approaches to communicate to the key stakeholders and increase the impact of international development interventions.

Global Engineers cannot stop at supporting evidence-based policy making, as policies will not achieve their goals unless their implementation is informed by iterative data collection and analysis. To contribute to data-driven decision making, engineers should be familiar with methods and tools that range from rigorous impact evaluation to implementation science and performance monitoring. Furthermore, engineers should understand context and environment, and choose and deploy the study design that enables learning and improvement. Engineers should also be aware of how impact measurement historically reinforced and perpetuated unequal power dynamics, and be prepared to counter unfair practices and structures through transformative accountability (Joyce, 2020).

Approach

This learning objective can be achieved through classroom learning. The course should include an overview of practices, approaches, and methods accepted in the sector; analysis of case studies showing the strengths and weaknesses of monitoring and evaluation and their impact on policy-making; project-based activities to train students to select and apply appropriate methods for specific scenarios; and active-learning techniques (readings, discussions and debates) that challenge students to develop a critical mindset to identify and counter unfair practices.

Applied Engineering Knowledge

Description

Global Engineering requires the ability to ***apply rigorous engineering practices and principles within a global context and specific local contexts, considering the unique requirements of resource-constrained settings.*** Global Engineering students' ability to apply foundational engineering knowledge is affected by their skills in Contextual Comprehension and Analysis, and Stakeholder Analysis and Engagement globally and locally. Examples of unique constraints and requirements are local building standards and codes, materials, equipment, and labor resources. Students should apply foundational engineering knowledge and skills to solve problems, analyze strategies, and design interventions. At the same time, students should be able to recognize when engineering is not part of the solution.

Motivation and Background

Communities around the globe are littered with abandoned or dysfunctional engineering projects, including water supply and sanitation systems, energy supply systems, and agricultural processing machinery. According to the United Nations Children's Fund (UNICEF), failure rates for WASH projects may be as high as 30-50% (Lu, 2019), and studies report non-functionality rates of 25-40% for water points in Sub-Saharan Africa (Banks and Furey, 2016; Foster et al., 2020). In many cases, these systems were designed and constructed by outside organizations without sufficient community involvement or planning for operation and maintenance. It is typical for communities to be handed engineered systems without accounting for their technical and financial ability to manage and repair these systems. In some cases, the engineered systems may not even align with community needs, priorities, or customs, leading to lack of adoption and rapid abandonment.

Engineering interventions and technological enhancements are critical to improving the standard and quality of living for all. However, technologies that connect inputs and outcomes have been woefully inadequate in applied experiences. Students must understand and apply their knowledge in the service of society in a partnered and collaborative workflow that benefits all stakeholders. This combination of technical expertise and understanding of cultural and societal conditions has been referred to as contextual engineering (Witmer, 2020).

Bloom's Taxonomy

As a core learning objective in a Global Engineering program, the proposed level of training is *mastery*. It could be argued that mastery (including the ability to synthesize new information and create innovative approaches) can be achieved through extensive practice and is context-specific to some extent (i.e. a certificate program can't expose students to all cultures and contexts). However, students should have sufficient understanding, background, and appreciation for context-specific engineering to allow them to achieve mastery in their careers.

Students should be apply rigorous engineering principles, analyze systems, and evaluate alternatives to arrive at the best solution for a given problem and its context. To develop sustainable engineering solutions, students need sound engineering principles and critical thinking skills amid the complexity of global and local contexts. Students need to understand that different engineering standards and guidelines prevail around the world, and that transferring U.S. standards and practices to other locations may lead to inappropriate, infeasible, or unsustainable designs. This requires metacognition that might not be developed in undergraduate engineering programs (i.e. an ability to critically reflect on standard U.S. approaches and skills developed in engineering coursework).

Approach

Programs will have to team with community partners domestically and internationally to facilitate a living laboratory and design space where students learn how to collaboratively apply engineering knowledge in service to society. This should take an approach where learning, ideation, and design development take place in a classroom mentored by a faculty member in collaboration with a community partner or client.

The partner will identify their needs and assess the proximate impact of potential technological interventions to meet those needs. Students can then work through the design process to identify options, determine the feasibility of each, and move through production of low- and medium-fidelity prototypes to determine a concept. Once the conceptual design is developed under tutelage of a faculty member with expertise in the field, it can be shared with the community partner for feedback and collaboration. The iterative process can then move through the design development phase, where the students, their faculty mentor, and the community partner collaborate to ensure an impactful and robust solution.

When feasible, a subset of the class or reconfigured team can participate with the partner to implement the designed solution. This will allow the students and partner to work through issues, operational challenges, anticipated maintenance plans, and further in-field refinement of the design. These phases link together to reinforce the design process and ensure the partner is empowered as a co-owner, stakeholder, and participant through the entire experience.

Project Design

Description

The Project Design learning objective consists of two complementary elements: ***(1) identify tools, methods and approaches for project design; and (2) design and assess programmatic Theory of Change and evaluation frameworks for global development interventions.*** Views on this learning objective mostly converge, but tools are divergent from a product development and business/ecosystem development standpoint. Most programs center around a human-centered design process, using, for example, open-source products from IDEO.org or the Acumen Foundation. Another community-based and implementation-focused resource is the IDEO human-centered design field guide. However, this must be applied in the context of a larger project design process. While the lean startup methodology is widely used, its application to mission-focused, global social ventures is less than perfect. Others are developing their own tools around the general ideas of Business Model Canvases, expanding on the work of Strategyzer. With respect to the Theory of Change, tools clearly converge. While there are many versions and levels of detail, they all begin with the "Need, If, Then, Then" methodology.

Motivation and Background

Engineers require training and expertise in areas beyond technical performance to achieve desired outcomes. These areas include the identification of relevant problem spaces, the design of projects and programs, and integrated monitoring and evaluation. Many projects succeed or fail at the planning stage, where team composition is developed, assumptions are made explicit, activities are mapped, and integrated monitoring and evaluation are created, including feedback and methods for course correction. Project design skills require perspective on what works in terms of teams, management, problem solving, and feedback.

Global Engineering work exposes professionals to places, people, and situations that might call into question their fundamental assumptions about the discipline, the process, the meaning of research and development, and the world in general (Downey et al., 2006). They might also develop a more nuanced understanding of technology's role and potential within complex and dynamic social, cultural, environmental, political, and economic systems (Allert et al., 2007). These experiences place students in contexts where they have limited prior knowledge and that require critical thinking, creativity, and application of theory-to-practice solutions(Dowell et al., 1994). Understand these factors is essential to project design.

Designing programs, projects, and critical assessments of Theories of Change requires project management experience – including successes and failures – and methods for monitoring and evaluation. Actionable, timely feedback to assess and critique Theories of Change and monitor project performance is critical(Thomas and Brown, 2021). Project design requires students to use skills from all the learning objectives while understanding how each skill should be tailored to the specific context. Students should adjust the application of project management, contextual comprehension, and stakeholder engagement skills based on project demands.

Bloom's Taxonomy

We expect that students would leave a graduate certificate with a *competence* level in Project Design. First, they should be exposed to relevant tools including designing a theory of change, identification of interventions, collection of available evidence, and creation of a monitoring and evaluation plan. Students should understand the motive for their use and their impact on development, and see examples of their application in projects. Then, they should gain competence in using the tools through application to projects in which they are involved.

Approach

While exposure can begin in the classroom, asynchronously if necessary, the best teaching method for competence is field-based practicum. Often when discussing human-centered design, Theory of Change, or business model canvases, the work is done in the comfort of a classroom. But such exposure to the tools ignores the difficulty of their implementation in global development settings where deep, immersive experiences help understand the tools' elements. Therefore, field experience is necessary to move from exposure to competence.

Such experience may be accompanied by setting-specific learning outcomes and measuring how well students develop key skills, understand essential concepts, and apply theory in challenging contexts (Driscoll and Wood, 2007; Halpern and Hakel, 2003). Team projects, reflective practice, and demonstration of skills (e.g., by creating a monitoring and evaluation system for the project) might be good options for assessment.

Project Management

Description

A Global Engineer should be able to ***apply project management skills and methods to lead a project from definition of the problem through conception and delivery of the solution,*** with an exit strategy and plans for its post hoc sustainability.

Project management in global engineering might include working across disciplines, cultures, locations, and resource availability to successfully manage the scope, schedule, and resources of the project. Aspects of project management that a global engineer should be competent in include: leadership, communication, risk management, project planning, budgeting, project evaluation, and time management (Udo and Koppensteiner, 2004). Project managers must adapt their approach to the specific context. Project management should consider the needs of all stakeholders to ensure that implementation is fair and ethical (Hartman, 2015; Hartman et al., 2018, 2014; Reynolds et al., n.d.).

Motivation and Background

Choices about project management implementation and adapting that strategy to context will influence a project's efficiency and success (Mattson and Wood, 2014). Project Management in Global Engineering differs from typical engineering in a workplace or academic setting. Flexibility is important for unforeseen circumstances in development work. A team needs to manage communication across cultures and disciplines, and possibly across technology availability. Project management software may not be available to all people involved in the project, so it is important that ideas are communicated across whatever methods are chosen. With many development projects failing, sustainability should be integrated early in the process for greater chances of long-term success (Jue, 2011).

Despite consensus that a project management strategy should be used, there is disagreement on the extent of planning and how flexible it should be. Extremely prescriptive project management can be burdensome and lead to counterproductive (Easterly, 2002) bureaucracy. Giving Global Engineers the skills to adapt project management to a particular context will prepare them to successfully carry out projects in the field.

Bloom's Taxonomy

Project Management in a Global Engineering program should cater to *competence*. This is an essential skill set across engineering applications,. Acknowledging this, opportunities to learn and apply this skill set in resource-limited settings will strengthen students' ability to operate in the Global Engineering context, and provide and strengthen skills applicable in other contexts. This will give engineers the tools to manage projects and alter strategies as needed.

Students should be able to describe the principles and phases of the project cycle management, and the challenges and constraints related to the multidisciplinary, dynamic, and complex nature of global development projects. They should use formats, tools, instruments, and procedures for planning, implementation, and evaluation of international development projects.

Therefore, students should be exposed to multiple methodologies and tools for planning, implementation, and evaluation used in global development to identify needs and promote social change. They should be able to develop a Theory of Change, a Logical Framework, and indicators to measure progress towards the achievement of an intervention's outcome.

Students should also be familiar with major funding mechanisms and processes for global development programs, and with best practices in developing grant proposals.

Approach

The Project Management learning objective can be achieved in the classroom by teaching fundamental principles (Charvat, 2003; Chin and Spowage, 2010), analyzing project management case studies(Kerzner, 2017; Martens and Carvalho, 2016), and creating proposals for a project management methodology. Students should understand the components of different project management methodologies and use cases (Jovanovic and Beric, 2018). Then, strategies for adapting project management to global engineering contexts should be taught. This curriculum will prepare students to manage projects in the field, but field experience is not necessary in training for this learning objective. The goal should rather be to enable students to understand and create a project management methodology for a project in the context of global engineering.

Beyond Project Design, this learning objective may be coupled with the Data-driven Decision Making learning objective (as aspects of project planning and management will be important for impact evaluation) and with qualitative learning objectives that support project management, such as Multidisciplinary Teamwork and Leadership, and Communication.

Multidisciplinary Teamwork and Leadership

Description

Global Engineers must be equipped to ***function on a culturally diverse and multidisciplinary team whose members contribute leadership and a variety of perspectives, create a collaborative and inclusive environment, and establish goals, plan tasks and meet objectives.*** Here, multidisciplinary refers to a mix of technical to social fields, where team members bring their skills and expertise to solve a commonly identified problem (Brown et al., 2010). Disciplinary diversity means teams include engineers with different specialties, social and natural scientists with varying sub-disciplines, and stakeholders with local knowledge and expertise. Multi-disciplinarity also brings awareness and openness to a myriad of research and project methods, pulling from across the disciplinary approaches. Members of such teams demonstrate respect for each other's knowledge and view problems and potential solutions through multiple perspectives.

Motivation and Background

Clearly, the complexity of development problems to be addressed – such as access to clean water, reliable clean energy, alleviating poverty and health issues, and many more detailed in the UN's Sustainable Development Goals 2030 ("Sustainable Development Goals," n.d.) – means no single disciplinary training can achieve equitable and sustainable solutions. Human well-being cannot be improved by technical means alone; moreover, technological development can introduce additional problems. Thus, the integration of social and technical factors is critical (Crow, 2007). Engineering educators note this need as well, and the importance to train engineering students to understand and incorporate cultural, social, and human factors into engineering projects (Amadei and Sandekian, 2010; Pérez-Foguet et al., 2018; Reina-Rozo et al., 2018). Engineers Without Borders-International recently proposed revisions to the International Engineering Alliance's benchmarks that incorporate social sciences into engineering, and for graduates to be able to think critically about engineering's relationship to society ("Impacting Engineering Education," n.d.).

Bloom's Taxonomy

We recommend that Global Engineering students achieve *competence* with respect to Multidisciplinary Teamwork and Leadership. To function effectively on a team with diverse backgrounds requires that each member learn aspects of other disciplinary approaches. Students should be able to highlight the difference between knowing different techniques within the disciplines, and being aware of other disciplines and how to engage with experts in those disciplines. Gaining enough knowledge in each disciplines includes being able to "speak the language" and be "conversant" in other disciplines, avoiding the mindset that certain knowledge is only for experts.

Approach

Approaches include classroom-based activities and field experience. Experiential and active learning gives students competence in working and leading multidisciplinary teams, keeping in mind the requirements of engineering curricula. Courses that engage students from other disciplines provide the opportunity for project-based learning where students work in teams and across disciplines to understand context, identify a problem, and design a solution. Students can also be supported in a classroom setting to examine different disciplinary approaches to research, inquiry, and knowledge construction, integrating those perspectives through discussion with faculty from different disciplines. A capstone project or field-based practicum with students and/or employees from other disciplines would build competence via the opportunity to engage with a multidisciplinary team, including local stakeholders.

Communication

Description

It is critical that Global Engineering students learn to ***apply and adapt written and oral communication strategies to reach and work with a diverse audience***. Communication skills include those standard to the engineering community (e.g. conference and seminar presentations, e-mails, reports, white papers, and journal articles) and skills beyond these but critical to other learning objectives, such as Multidisciplinary Teamwork and Leadership, Project Design, Project Management, Stakeholder Engagement and Analysis, and Data Collection and Analysis. These learning objectives, and Global Engineering more broadly, require the ability to communicate effectively and respectfully with diverse audiences, using appropriate communication strategies.

Motivation and Background

It is generally agreed across engineering programs that communication skills are critical for students' careers. The emphasis, however, is typically on technical communication skills, whereas Global Engineering relies heavily on non-technical communication as well.

The Accreditation Board for Engineering and Technology (ABET) identifies communication as a required outcome for baccalaureate degree programs in engineering. More specifically, upon graduating, students should be able to "apply written, oral, and graphical communication in both technical and non-technical environments" and "identify and use appropriate technical literature" (ABET, 2017). Despite efforts by engineering programs to develop students' communication skills, studies find that employers report dissatisfaction with engineering graduates' communication skills (Donnell et al., 2011; Missingham, 2006). Given these findings, graduate Global Engineering programs should not assume that incoming students have sufficient technical communication skills, much less those needed in interdisciplinary, intercultural environments.

Communicating effectively and respectfully across audiences, contexts, and desired outcomes requires oral and written communication skills, and elements such as listening, and interdisciplinary and intercultural skills(Riemer, 2007). Listening and intercultural communication skills are particularly helpful in cross-cultural humility and pursuit of life-long learning. These skills equip students to engage with stakeholders, carry out qualitative data collection, and work in or lead interdisciplinary and intercultural teams. They also strengthen students' ability to communicate technical knowledge, such as results of quantitative data analysis, to people in other disciplines, a common gap in engineers' communication skills.

The ability to communicate beyond disciplinary boundaries enables engineers to participate in public policy (Mendoza-Garcia et al., 2012). In educating Global Engineers and working toward professionalization of the field, educators, researchers and practitioners should follow the examples of the global health and economics fields' achieving influence in policy (Thomas et al., 2021). Effective communication is critical to supporting informed decision making.

Bloom's Taxonomy

We propose that Global Engineering students achieve *competence* across written and oral communication skills, and *mastery* of the skills subset most relevant to their career path. Students should be able to research, write, and format clear reports that articulate the research process and its findings. They should adapt their writing style and means of presenting the results of data analysis according to target audience and context. These should carry over to verbal communication, with students able to present the results of research and data analysis, communicate technical information, and adapt this communication to audience and context.

Regarding the learning objective of Contextual Comprehension and Analysis, students should be able to construct and present logical arguments, both orally and in writing. Towards that end, they should express their opinions, relay supporting facts, and articulate their argument (Missingham, 2006). That said, students should also be able to listen to counter-arguments and respond appropriately and respectfully, with a willingness to learn from others.

Approach

These communication skills should be strengthened throughout a Global Engineering graduate program, both inside and outside the classroom. Depending on the course, students should have the opportunity to hone their writing skills through written reflections, or technical, lab or research reports. They can improve their conversation and presentation skills through group discussions, debates, and presentations. Opportunities to improve verbal skills should emphasize active listening and taking others' opinions into account. These should be tested and strengthened through multi-disciplinary teamwork and stakeholder engagement in a term or field-based project.

Climate Change, Sustainability, and Resilience

Description

Global Engineering students should be able to ***identify and analyze the climate change dimensions of global inequalities and describe pathways to improve sustainability and resilience, including attention to and approaches at local, regional, national and international levels***. To ensure that students learn how climate change, sustainability, and resilience inter-relate and impact global development, a Global Engineering graduate program should examine the social, economic, political, cultural, and environmental aspects of climate change and their interplay. This should include identifying and discussing the inequities that amplify the adverse effects of climate change, particularly in the global development context, including those created by colonialism and capitalism. Students should be confident in discussing the trends and forces instigated by non-sustainable growth and development shaping our world. Through Global Engineering education, they should understand a sustainable society requires and the role of engineers in achieving these conditions.

Motivation and Background

Climate change exacerbate and accelerates environmental damage and economic stress globally. The World Health Organization conservatively projects over 250,000 additional deaths each year between 2030 and 2050 attributable to climate-change-driven increases in heat waves, diarrhea, malaria, and malnutrition caused by crop failure. A further 100 million people could be pushed back into poverty by 2030 because of climate change. Today, two billion people live with chronic water stress and four billion experience water stress at least one month a year. One-third of agricultural soils globally are degraded and two billion people face food insecurity. The quality of the food we eat, the air we breathe, and the water we drink is under threat from climate change.

Global development consists of human development – the process of improving people's well-being and increasing their freedoms and opportunities – and sustainable development, which "meets the needs of the present without compromising the ability of future generations to meet their own needs." Climate change is already negatively affecting the well-being of people, with the greatest impacts experienced by low- and middle-income countries (LMICs). Further, climate change is undoing progress in human and sustainable development in LMICs, and must be considered in planning efforts, with emphasis on resilience in communities that will experience the impacts of climate change in the foreseeable future.

Bloom's Taxonomy

Students should reach the *exposure* level with respect to Climate Change, Sustainability, and Resilience. They should be familiar with global trends, policies, and goals. More specifically, students should be able to describe and discuss the scientific consensus established through the International Panel on Climate Change and its complexities and uncertainties. These discussions should be framed in the context of global development and the impact of climate change on development interventions' effectiveness. Students should be able to define the 2030 Sustainable Development Goals, explain their history, structure and relationship to ecosystem health and human wellbeing, and discuss the sociological, economic and political factors that influence work towards achieving the goals. More broadly, students should be able to identify and discuss the historical and current relationship between climate, the environment and global development, and debate the effectiveness of key strategies and policies, and their implementation to achieve a sustainable relationship between the three.

Approach

These concepts are best explored in the classroom, through a combination of lectures and small group discussions conducive to debate. Some suggestions for classroom-based activities to achieve this learning objective include: review of IPCC climate reports, review of UN Conference of Parties agreements, identification of the disparities associated with climate change, case studies with existing technological solutions to help students develop a critical eye for engineering technologies to support resilience and climate change adaptation and mitigation; case studies covering current disasters (climate change, natural disasters, etc.) to contextualize and apply lessons learned; and intentional self-reflection exercises to allow students to explore their own sociological understandings of disaster.

Global Health

Description

Global Engineering students should thus ***understand the guiding principles of global health practice, be able to apply lessons learned from the implementation of public health interventions and evaluations, and understand how the public health sector influences and evaluates development programs and projects.*** The field of Global Health has a long history of research through collaboration between low- and high-income countries, critical for global development. Lessons from the sector are relevant to Global Engineering students planning to engage in similar collaborations and to work in global development more broadly. In completing a graduate program in Global Engineering, students should have foundational understanding of the unequal distribution of the global burden of disease and how it intersects with food security, water access, and energy access.

Motivation and Background

Global Health addresses disparities in disease determinants and burden, especially in low-income communities. The Consortium of Universities for Global Health defines the discipline as "an area for study, research, and practice that places a priority on improving health and achieving equity in health for all people worldwide. Global Health emphasizes transnational health issues, determinants, and solutions; involves many disciplines within and beyond the health sciences and promotes interdisciplinary collaboration; and is a synthesis of population-based prevention with individual-level clinical care" (Koplan et al., 2009) As a field, it is intentionally multidisciplinary. Successful practice requires familiarity with community health, behavioral health, epidemiology, and biostatistics principles while incorporating public policy, environmental engineering, program management, social enterprise, and business skills.

Many Global Engineering projects are motivated to address the unequal distribution of disease determinants and burden, and Global Engineers often work in the same context as and with global health practitioners. To reduce the lobal burden of disease, engineers must understand the types of pathogens endemic in the communities where they work and the diseases that cause the greatest burden for the community and local partners. Global engineers should have exposure to societal problems while developing and implementing technological solutions, and should understand the broader implications of their solutions for addressing the public health needs of the community.

Global Health also provides frameworks and processes useful for Global Engineers, including developing study protocols, obtaining approval from institutional review boards (IRB) to protect human subjects, study design (e.g. sample size calculations), data collection, pre-specifying statistical analysis plans, and data management and sharing plans. These are discussed in the sections on Data Collection and Analysis and Data-driven Decision Making.

Bloom's Taxonomy

We suggest a training level of *exposure* for this learning objective. Students should be able to use the Global Burden of Disease data to describe and interpret health disparities between and among low-, middle-, and high-income countries. Understanding disease burdens will provide knowledge to assist students in advising community partners on intervention and program choices. For resource-limited settings, students should be able to describe interventions and evaluations, including community water supply, household water treatment, sanitation, indoor air quality and energy systems. They should be able to identify design requirements and standards for global health interventions. Exposure to global health methodologies and case studies will enable students to know available study designs, methods, and tools from the global health discipline applicable to their project or research.

Approach

We recommend a classroom-based approach, using a combination of lectures, readings, written reflections, case studies and a term paper. Lectures would cover: the major causes of the global burden of morbidity and mortality, food systems, pathogens of concern transmitted through the environment, environmental controls, study and survey design, data management, ethics, protection of human subjects, basic biostatistics, and epidemiology concepts. Assigned readings and written reflection would support lectures by requiring students to engage with and explore questions or concepts presented in lectures and readings. Case studies on successful and failed interventions would let students apply the concepts covered in lectures and readings, prepare written reflections, and discuss the lessons learned. For the term project, we recommend that students choose a research topic, conduct a literature review supported in part by a review of the Global Burden of Disease database managed by the Institute for Health Metrics and Evaluation, and write a proposed study protocol that involves human subjects, IRB requirements, data to be collected, methods, sample size calculations, ethical implications, and an analysis plan.

Development Economics

Description

Global Engineering students should be equipped to ***examine historical and current development economics theories and their influence in and impact on global engineering and its efforts towards global poverty reduction.*** Global Engineers must understand that neither technological enhancements nor economic policies will alone solve underlying inequities and marginalization. Students must understand the themes and issues behind economic development. This includes recognizing poverty, understanding its underlying causes and systemic perpetuations, and using this knowledge in their expertise to demonstrate how engineering can contribute solutions. They must be versed in the vocabulary, theory and principles of economics, and how these apply to communities in which they are engaged.

Motivation and Background

Poverty does not originate from a single factor, nor does it happen equally around the globe. Likewise, no single policy or strategy sets economic development in motion. No general rules guarantee a path towards development (Bhorat and Naidoo, 2019). As Denis Goulet stated, development "aims at freeing men from nature's servitudes, from economic backwardness, and oppressive technological institutions, from unjust class structures and political exploiters, from cultural and psychic alienation – in short, from all of life's inhuman agencies" (Goulet, 1979). Development economics studies the path to this liberation. It analyzes the transformation of countries from the Global South into more prosperous nations. Theories and methods created by economists help practitioners such as Global Engineers determine the policy and practice to be implemented for a circumstance that will contribute to reducing poverty (Perkins et al., 2013).

Successful economic development is elusive in many countries of the Global South. Considerable intellectual effort spent on this issue over many decades yielded mixed results. A recent and alarming trend shows that inequality has widened across all countries, rich and poor alike (UNDP, 2019).

We know that countries can improve the standard and quality of people's lives even under adverse circumstances, and that countries made progress towards the Sustainable Development Goals with even modest growth in income. However, countries with stronger economic gains over the decades failed to make similar progress in life expectancy, poverty alleviation, schooling, and overall living standards.

Bloom's Taxonomy

Given that Development Economics is not the main thrust of an engineering education, students should have *exposure* to the main themes, recognize terminology, and comprehend the concepts being presented. The structure and goal of this topic are that students understand the framework around their projects and he systemic issues that hamper the economic progress of a community, nation, and region.

Development Economics should address the main topics based on a theoretical framework applied to real-life examples, focusing on engineering's contribution to solutions. Some questions to address include: why developing countries have poor health, high child mortality, extreme poverty, low levels of education, and high levels of child labor; and which, if any, policies are effective in alleviating these problems. Emphasis should be placed on analyzing current economic issues and policies in their historical context. Economic reform, agricultural and industrial development, income distribution, health and education, and international economic relations should all be scrutinized on a macro level to identify context-specific responses.

Approach

We propose to achieve this learning objective through a 1-credit equivalent of content, whether a separate module or built into a larger course. Analysis and in-class discussions should be guided by a multi-sectoral approach. Delivery of the main concepts through lectures should be followed by participatory, active learning discussions based on readings and completion of discussion facilitation sheets. These would be used by a group of students appointed to guide the class through supervised discussion of the reading material, with groups rotating to ensure that each student takes part in leading discussion. Students should also be placed on teams to discuss and/or debate the efficacy and effectiveness of various approaches. While the main evaluation will be through written assignments and participation, examination instruments such as tests and quizzes may be employed to measure understanding, competency, and grasp of the material.

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