Development of a Global Design Education Experience in Bioengineering Through International Partnerships

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The field of engineering is increasingly appreciating the value of diversity for innovative design solutions. Successful engineering depends on our ability to explore constrained parameter spaces for finding the best solutions, and more diverse minds and experiences enable us to explore the entire potential solution space more thoroughly, more quickly, and more creatively. With a goal to expand the diversity of experiences and mindsets in our undergraduate bioengineering curricula, Arusha Technical College (ATC) in Arusha, Tanzania and Clemson University (CU) in Clemson, South Carolina, U.S., have partnered together over the past 5 years to provide intercontinental educational opportunities for undergraduate students, graduate assistants, and faculty. In 2018, CU and ATC collaborated on an international design course targeting undergraduate students in biomedical engineering focused on global health solutions for resource poor communities. Undergraduate students from ATC and CU collaborated on design projects through formal videoconferenced group meetings, e-mail, and various social media platforms. The year ended with a joint design symposium in Arusha where the students presented on their work in a public poster forum. This successful ATC-CU Global Health Design Collaboration pilot year provides a solid model upon which to build. Students reported overall positive experiences and plans to continue in their curriculum to graduation, as well as some ATC and CU students changing their career direction to include global health initiatives. [DOI: 10.1115/1.4045112]

Introduction

The goal of this paper is to describe the development of an on-going international collaborative biomedical engineering design program between Clemson University (CU), Clemson, SC, and Arusha Technical College (ATC), Arusha, Tanzania. We will highlight the program structure, challenges, and initial outcomes, as well as propose future directions for the program to ensure sustainability and student success.

There was a time when getting hired in the global job market was a sure thing after earning a degree in engineering. Passing a series of professional and/or licensure exams were the qualifications necessary for entering an engineering career. The profession as a whole has evolved in the last 50 years, as have the skillsets needed for professional success. The role of engineer still requires strong analytical, integrative, and problem-solving skills; however, the skillset of a successful engineer in today’s world includes the ability to work in multidisciplinary teams, communicate well, and understand the economic, social, environmental, and international context of their professional activities [1–5]. Having its founding in the late 1960’s, biomedical engineering (BME) as a discipline has developed alongside a changing global mindset demanding a greater need for multidisciplinary communicators and societal thinkers. BME is somewhat different than the more classical engineering professions; at its core, a BME education follows a multidisciplinary approach that embraces a wide range of science, technology, engineering, and mathematics (STEM) and focuses on problem solving in human healthcare [6]. Indeed, the educational development of engineers with international mind-sets is vital to a nation’s industrial strength and to the ability of engineers to serve as technology and policy decision makers [7]. It is in this context that university BME departments have begun to embrace international partnerships and opportunities that provide students more immersive cultural experiences and better prepare them for their future careers [8,9].

Like many of our peer institutions, CU and ATC recognize that the challenges confronting the modern world tend to be global in nature. Global healthcare challenges are increasingly becoming local healthcare challenges, as diseases and natural disasters are not contained by borders. Developing and integrating global competence skills into a compacted curriculum is a challenge facing many higher educational institutions. Global health research and development can greatly benefit from international university-based partnerships focused on providing an inclusive, interdisciplinary engineering education that fosters innovation in the local public health context [10]. Collaborative international partnerships between universities can encourage a multidisciplinary approach to global health that embraces STEM solutions and accelerates the establishment of engineering research programs for low-income partners [6,11,12].

Global health collaborations provide tremendous service-learning opportunities for students in STEM. Student participation...
yields positive effects on measures of academic performance, critical thinking skills, values, ethics, self-efficacy, and leadership [13,14]. Prior studies have shown additional benefits of international experiences to programs. For instance, several studies examining student retention and educational outcomes have demonstrated that under-represented students, first generation, low income, racial and ethnic minorities, and students groups with greater risk of attrition than other student groups experience increased educational resiliency, increased feelings of personal meaning, and enhanced critical consciousness by engaging in international service learning experiences [9,10].

Planning for Institutional Collaborations

With a goal to expand the global experiences and mindsets in our undergraduate bioengineering curricula, ATC and CU formed a partnership to provide international educational opportunities for undergraduate students, graduate assistants, and faculty. This global health partnership is now in its fifth year and has produced and successfully implemented innovative practices in teaching and design at ATC and CU. From this work, we have produced new biomedical devices and enhanced curriculum at both institutions, and we have had a measurable impact on our students. We describe the program’s development in this paper.

The CU Bioengineering Department has been collaborating with partners in Tanzania for the past 10 years with undergraduate and graduate students participating in design projects with clinical collaborators in the U.S. and Tanzania. The program was started to address the growing student interest in working on projects relevant for low-resource settings. Through interactions between engineering and clinical faculty in the U.S. and Tanzania, several collaborations were established to allow for needs-finding, design, and prototype development projects. This included CU Bioengineering faculty, clinical faculty at the Medical University of South Carolina and Muhimbili University in Tanzania, and both clinicians and engineers at Haydorn Lutheran Hospital in Tanzania. Starting with the 2010–2011 term, Clemson students journeyed to Tanzania during their winter and summer academic breaks. These initial trips to Tanzania with clinical collaborators focused on clinical needs finding in rural and urban hospital settings. The program was established at CU as a formal Creative Inquiry course (BioE4510-010: Designing Medical Devices for Developing Countries) for undergraduate students in January of 2011, starting with four enrolled students. Clemson’s Creative Inquiry program aims to engage undergraduates in research and design projects through team-based learning. These for-credit research courses are an option for technical elective credit in the Bioengineering curriculum. The BioE4510 course can also count toward technical elective credit in many other STEM majors on campus, including electrical and computer engineering, mechanical engineering, and biological sciences. This Creative Inquiry course, now called Global World Health, quickly grew to ten students in Fall 2011, and has since had sustained enrollment of 15–20 students per section each semester. In June 2013, through interactions with non-profits Engineering World Health (EWH) and BETA International, faculty and students from CU met with the faculty and staff at ATC for the first time to talk about curriculum and possible collaborations. The 2018–2019 academic year had 42 total undergraduate students participating: 2 freshmen, 10 sophomores, 18 juniors, and 12 seniors from the following majors: bioengineering (both materials and electrical concentrations), electrical engineering, computer engineering, computer science, biochemistry, genetics, microbiology, and general engineering. Other majors have been represented in the past including a variety of other STEM disciplines (e.g., mechanical engineering, business, and communication majors).

ATC established one of the first Electrical and Biomedical Engineering training programs in East Africa in 2012 at the Diploma level, and they launched a Bachelor program in 2015. The Diploma program is similar to an engineering technology degree in the U.S. The programs are accredited by the Tanzanian National Council for Technical Education, part of the Ministry of Education and Vocational Training, for training engineering technicians and engineers. Students in ATC’s program undergo standard STEM coursework, as well as internships and shadowing in clinical settings with engineering staff. The programs end with a year-long capstone design project, where students build and test a prototype device to address a need. Similar to CU’s Creative Inquiry program, students at ATC also have the opportunity to work on self-driven projects through elective and club activities.

Initial discussions between ATC and CU faculty focused on curriculum harmonization and teaching opportunities. Over the past 6 years, faculty and graduate teaching assistants from the CU Bioengineering Department have traveled to ATC for 2 weeks each summer to teach short-courses in Design Thinking and Anatomy and Physiology. The Design Thinking course was modeled after a typical “Need-Define-Prototype-Test-Reflect” design cycle, and it was centered on needs that were specific to the ATC community. Innovation and entrepreneurship were also stressed. These topics were very well received, as they were initially unfamiliar to ATC’s standard method of design, which was more classically defined as “specify-build-test.” The Design Thinking course facilitated ATC student teams (~35 students per year) through a design cycle that included a mixture of lecture and hands-on applications covering empathy, problem definition, ideation, and prototyping. Each team of 3–5 students brainstormed dozens of health-related problems, interviewed local stake-holders, identified a critical problem statement, generated dozens of potential solution ideas, designed a final solution, constructed a “shoe-string” prototype (e.g., a prototype made up of paper, cardboard, string, pipe cleaners, etc.), and presented their solution to ATC peers, faculty, and administrators.

Using the experiences and lessons learned from the short course teaching, faculty from both institutions were confident that engaging multidisciplinary teams of students in a project-based curriculum framework could be successful [15–18]. The project-based curriculum is well suited to developing student engineers’ independence and creativity. Global projects in particular reinforce why the engineering profession follows standards and practices regardless of geographic location. Students learn how to define project requirements and manage deliverables just as they would in industry [19–22]. Following the examples of successful international collaborative BME programs from Rice University [18], Duke University [23], and Georgia Institute of Technology [24], both CU and ATC faculty recognized the biggest challenge common to all these programs that include a service learning travel component: funding.

The benefits of service learning on student outcomes, as well as the inequality in the demographic of students accessing these opportunities have been well documented [5,13,17,25,26]. Funding tuition, travel, and expenses is a challenge programs must deal with in balancing service learning opportunities with a socio-economically diverse student body [27,28]. Taking this into consideration, the CU and ATC faculty sought to utilize telecollaboration and social media as platforms to establish the international collaboration. The intended outcomes for student learning mirrored outcomes typically delivered in BME design courses: communication skills, ability to work in diverse teams, problem solving, etc. The realistic initial goals of this pilot program were humble in scope:

(1) To virtually connect student design teams on a regular basis as defined by the syllabus;
(2) Through faculty collaboration, to guide students at both institutions thru the calendar of events and design deliverables rooted in a BME design course semester.

Though simple enough on paper, there were significant logistical arrangements and commitments that needed to be solidified in order for these humble goals to be met in the pilot year. Solidifying the partnership and demonstrating further investment in capacity building in Tanzania and South Carolina, the institutions drafted and formally signed a memorandum of understanding.
The MOU established a framework to facilitate academic programming (e.g., distance learning and internships), research and training exchanges, collaborative research and design projects, and exchanges of institutions' professional information (e.g., curricula). In addition, the MOU included addendums for mutual nondisclosure agreements and details to minimize administrative barriers for student and faculty exchanges.

ATC and CU administrators and faculty acknowledged the need to have the ATC Biomedical Engineering Program accepted as an equivalent engineering program on par with internationally recognized engineering programs. ATC engineering programs are accredited through the Tanzanian Ministry of Education and Vocational Training and go through rigorous continual review. In the summer of 2016, ATC hosted Clemson Bioengineering faculty and staff in a visit to the ATC campus to meet the faculty and students as well as review curriculum. Experienced in the assessment and accreditation process facilitated under the ABET criteria, CU faculty and staff made recommendations and assisted the ATC faculty and administrators to ensure that the curriculum and assessments already in place were in line with ABET-type standards.

Planning for Joint International Student Design Experiences

The following year in July 2017, ATC hosted a planning summit where faculty and staff from both institutions laid the groundwork for the ATC and CU Global Health Design Collaboration. The premise of this collaboration was for students at both institutions to connect virtually (and eventually in person), work on design teams targeting preselected global health design projects, and share their experiences and ideas as the design process takes place over the year. Formally, we defined the following goals for the Global Health Design Collaboration:

- Enhance the collaborative academic environment:
  - compare engineering design methodology between the institutions,
  - enhance marketability of ATC and CU students in a competitive global market, and
  - strengthen the engineering identity among staff and students at CU and ATC.

- Develop entrepreneurship skills:
  - define projects based on community-based needs finding,
  - translate technology to be implemented in communities, and
  - facilitate the process for students to start their own companies.

- Promote collaborative research between faculty:
  - identify possible cross-over of research capabilities and resources and
  - initiate research projects together.

Student activities were defined to provide a foundation for addressing global problems related to health care disparities in low-resource settings and understanding the challenges specific to low resource health design. Faculty and staff from both institutions generated a list of design projects deemed suitable for both CU and ATC undergraduate students. From that list, the following projects were selected for their potential success as global health design projects:

1. instrumented walking cane for vision-impaired,
2. portable patient monitor,
3. infant warming system, and
4. electrosurgery and cauterization instruments.

Project selection criteria were:

- student skill set and interest,
- accessibility of parts and instrumentation,
- expected budget,
- (4) time to completion in academic year,
- (5) complexity of goals,
- (6) impact on education of student, and
- (7) relevance to community need. While students were provided these topics to focus their projects, students utilized background research and needs assessments to decide the actual design path their projects followed.

ATC student participants for the pilot year were recruited from the biomedical engineering students in both the ATC Electrical and Biomedical Engineering (EBE) Diploma and Bachelor programs. The Bachelor students were in their second or third year and were already involved in the design process for one of the selected projects as part of their required courses or were considered advanced enough in their studies to participate in the design process. In addition, four motivated students in their last year of the Diploma program were selected to participate, as their fabrication and design skills were deemed on par with the Bachelor students. CU students were recruited through volunteer participation in a new Clemson University Creative Inquiry Global Health Collaborative Design course (BioE4510 Sec. 31). It should be noted that the ATC EBE Bachelors program and the CU Bachelor students in Bioengineering with Electrical concentration had very similar curricula and course requirements, which made discussion of basic material among students fairly straightforward.

By far, the most important agenda item completed at the July 2017 planning summit was the calendar of events dictating the next year of the program. Using academic calendars from both institutions, including different calendars for the ATC Diploma program and Bachelor program (Table 1), the faculty and staff set

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity</th>
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<tbody>
<tr>
<td>September 8</td>
<td>Meeting #1: Faculty/student conference call</td>
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<tr>
<td>October 6</td>
<td>Meeting #2: Faculty/student conference call</td>
</tr>
<tr>
<td>November 10</td>
<td>Meeting #3: Faculty/student conference call</td>
</tr>
<tr>
<td>December 8</td>
<td>Meeting #4: Faculty/student conference call, Developing design prototypes</td>
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<tr>
<td>January 19</td>
<td>Meeting #5: Faculty/student conference call</td>
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<tr>
<td>February 9</td>
<td>Meeting #6: Faculty/student conference call, Prototype presentations, EWH prep</td>
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<tr>
<td>April 6</td>
<td>Meeting #7: Faculty/student conference call V/V testing results</td>
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<tr>
<td>May 3</td>
<td>Meeting #8: Final presentations showcase</td>
</tr>
<tr>
<td>May 30</td>
<td>EWH competition deadline</td>
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<tr>
<td>June, first 2 weeks</td>
<td>Global health design symposium in Arusha (visit by Clemson Dean to ATC)</td>
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Table 1  Institutional academic calendars 2017–2018

<table>
<thead>
<tr>
<th>Institution/program</th>
<th>First semester</th>
<th>Second semester</th>
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<tbody>
<tr>
<td>Clemson University</td>
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<tr>
<td>ATC Diploma program</td>
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<tr>
<td>ATC Bachelor program</td>
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Table 2  ATC-CU global health design collaboration activities calendar for 2017–2018

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the next year’s specific virtual meeting dates and times (Table 2). In addition, the design project deliverables that students share in semiformal presentations were established. Also added to the calendar and project deliverables were deadlines and outputs required for the EWH design competition, and all students were encouraged to prepare an abstract submission. Generating the calendar of events was a cultural learning experience for everyone as academic calendars were compared, country-specific holidays, and events were noted, and adjustments were made for any conflicts.

The virtual meetings on the calendar (Table 2) were held online using ADOBE CONNECT web conferencing software at 8:00 EST/EDT for CU and either 15:00 or 16:00 EAT for ATC, depending on daylight savings time. CU maintains an institutional license that included the entire suite of distance learning modules and hosting requirements. ATC was able to access the platform without purchasing software or licenses. Internet connectivity at ATC was not a concern as the campus is connected to the country’s telecom service through a dedicated 4 gigabit bandwidth fiber optic service line.

The culmination of the year’s activities was the Inaugural Global Health Design Symposium at ATC in June 2018. The plan for this event included a research poster forum displaying the students’ work from both institutions, as well as a series of professional development workshops presented by faculty and staff.

**ATC-CU Global Health Design Pilot Year**

CU’s standard academic and ATC’s Diploma program calendars both started in August 2017. This was much before the ATC Bachelor program in its pilot year, which started at the end of October 2017 (Table 1). CU faculty used this time to recruit students to the Creative Inquiry course and generate interest in the specific projects. Recruited students performed thorough background research into the published needs and design requirements to consider for resource poor settings. CU students presented their findings and preliminary designs to the faculty at both institutions in meeting 1 and meeting 2 (Table 2). As ATC Bachelor students returned from break, before the ATC academic year began, they also began participating in the meetings by introducing themselves and sharing design ideas and motivation for particular projects. For the first year, the teams had 3–4 CU students matched with 2–3 ATC students.

The November 10 meeting was the first meeting scheduled with student teams from both institutions presenting their projects through the ADOBE CONNECT platform (Fig. 1). Students’ deliverables included oral presentations on video camera as they presented their slide package, introducing themselves and detailing their projects from background through preliminary design to bill of materials. As each student team finished, the audiences at both institutions were given the opportunity to ask questions and propose ideas. Faculty at both institutions encouraged students to interact outside of the formal meetings, suggesting they utilize whatever media platforms they found most comfortable. Students began interacting on social media platforms Facebook and WhatsApp, sharing quick videos of the projects in action, design sketches, and brief discussions on resources in Tanzania. While interactions on social media were not formally documented during this pilot year for quantity or content, it was noted that students who were active social media users were more apt to interact online. This led to our development of social media pre- and post-surveys for our program’s second year to gauge expected versus actual online participation. The survey was given to CU students, following institutional review board approval.

**Design Symposium**

As the year progressed, ATC and CU made plans for the end of year design symposium to be hosted at ATC. Funding student and faculty travel to Tanzania was a large barrier to success of the symposium. However, CU faculty were able to compile the necessary funding by tapping multiple sources at the university including the CU Creative Inquiry program, CU Honors College, the College of Engineering, Computing, and Applied Science Dean’s Excellence Fund. This allowed at least one student representative from each team was able to attend. The ten students who traveled to Tanzania were fully supported so as not have cost be a barrier for participation.

The Inaugural ATC Clemson Global Health Design Symposium was held on June 11–12, 2018 in Arusha, Tanzania. There were ten Clemson student participants and ten ATC student participants (seven Bachelor, three Diploma) who presented their project posters at the symposium. In addition, five Clemson faculty, including the Dean for Undergraduate Education from the Clemson College of Engineering, Computing, and Applied Science and six ATC faculty and staff put together workshops, presentations, and demonstrations. The 4 h poster session (Fig. 2) was open to the public and was attended by well over 200 people total, including the...
Rector of Arusha Technical College, local representatives of the Ministry of Education, and the members of the press. Students and their work were featured on the news locally and nationally in Tanzania.

Hosting the symposium at ATC was significant, as this was the first opportunity for ATC students to present their work in an academic forum to the public. The faculty and staff from both institutions conducted hands-on workshops on engineering team building, design thinking, medical device reprocessing and recycling, open-source computational resources, and graduate school programs and admission processes. Feedback from participants was uniformly positive. As noted by the Tanzanian media, the symposium was a locally impactful event that has enhanced ATC’s reputation as a highly regarded engineering institution in Tanzania. The year of collaboration culminated in three conference abstract submissions to the Biomedical Engineering Society Annual Meeting and three abstracts submitted to Engineering World Health.

Collaboration Sustainability and Assessment

The ATC and CU virtual collaborative design course is now in its second year, connecting student design teams from both institutions onto projects focused on global health technologies in resource poor locations. Changes implemented in the current year include allowing students more freedom in picking project topic area and including teams working on outreach activities. The outreach activities are aimed at increasing awareness of engineering to K-12 students. One current project example is the Bionic Hand teams at ATC and CU (Fig. 3). Through e-mail introductions and informal Skype video calls, students were able to collaborate on all parts of the design from the electronic controls (Fig. 3) to the materials and fabrication of an upper limb prosthetic using locally sourced, low cost materials readily found in the U.S. and Tanzania. Similarly, the Elephant Dentures teams at ATC and CU are developing an outreach module suitable for elementary level students in both the U.S. and Tanzania, collaborating on the design of elephant-scale dentures and using it during outreach events to promote oral health.

We assessed student perception of telecollaboration tools, for example, social media or other communication methods, using precourse (Figs. 4 and 5) and postcourse surveys (Fig. 6). CU students in the second year were invited to fill out the precourse survey in order to gauge their experience working with social media and telecollaboration and working with faculty and students in other countries through study abroad. As might be expected, prior to this course, students had a diverse experience using social media in their personal lives and moderate experience using collaborative software from other courses.

The postcourse survey gave space for respondents to express any positive or negative experiences they had from participating in the collaborative course. Feedback regarding changes to the weekly meeting format for CU students and more opportunities for mentor interactions were noted. There were several positive comments related to the goals of the class. For instance, a positive outcome experience from a student illustrates one of our unofficial goals for this collaborative experience.

“In the two semesters before the trip, I had the opportunity to meet (through e-mail) and discuss our project with the ATC students collecting data. My team was able to gain valuable insight from the team at ATC who have a different point of view than our own. When I went to Tanzania, I was able to actually meet these students and build our relationship as a team, which I think was the most positive experience from the past year.” Excerpt from postcourse survey.

We will use the input from the pre- and postcourse surveys to further develop student outcomes and assessments of the student experiences. In addition to these surveys, students provided feedback on the course through the standard university course evaluations every semester (both at CU and ATC). In general, students in the survey commented on the meeting formats and issues with international communication. Overall, the students responded very positively to the course in terms of its “effectiveness” at meeting learning objectives, and they unanimously noted that they would recommend the class to friends. Future work will be performed on further analyzing the online interaction of the students as they relate to student outcomes. Further assessments of student outcomes postgraduation are currently in development. The annual ATC Clemson Global Health Design Symposium will allow for the opportunity to share and consolidate student outcome data between both institutions. Plans are in place to collect and consolidate data identifying successful technology transfers and products brought to market as well as student postgraduation employment.

Challenges: Communication and Funding

Even in the best of circumstances and with contingencies in place, relying on commercial internet-based communications to connect across continents led to some unanticipated events. Global commercial network outages, bandwidth restrictions, and transmission lag affected the collaboration in both years, as did weather interruptions (e.g., hurricane closures) and power outages. Contingencies, including utilizing different video conference platforms, were difficult to employ in the moment, and rescheduling
meetings proved even more difficult with the differing academic calendars. Going forward, faculty are planning more engagement on student-selected, social media platforms, and evaluating student engagement through more qualitative means in addition to course deliverables [28].

Unfortunately, many international collaborations have limited sustainable impact and growth in the developing region due to various detracting factors [6,29]. The largest barrier to continued sustainability of global health collaboration between institutions is funding support [30]. While globalization has brought internet
access to remote locations and affordable travel to much of the world, the establishment of these connections still requires significant financial and time investment. It is no surprise that the health initiatives. This collaborative course development was and still is a work in progress, with faculty and staff revisiting delivery methods, content, and student outcomes each summer. This program’s impact on student development was achieved with an extremely limited budget and resources and merits further expansion and funding.

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