Impacts of Prosthetic Innovation in Ecuador Study Abroad Course

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Abstract—Biomedical engineering (BME) students typically have a schedule filled with specific course requirements, leaving little room for spending a semester studying abroad. We established a new short-term BME study abroad course, partnering with a non-profit healthcare organization that provides high-quality prosthetic care to underserved populations. This innovative study abroad course was met with great student demand. The impact of this short-term study abroad course is increased by developing year-long BME senior capstone design projects based on the needs identified throughout the experience in Ecuador. Shortly after the conclusion of spring semester, students and two BME faculty/staff traveled to Ecuador. During the work week, the students participated in small teams in patient evaluations, castings, fabrication of prosthetics, device fittings, rapid prototyping-testing iterations, and post-prosthesis gait training with physical therapy. Weekends included guided cultural activities. Each student maintained a journal that reflected observations and insights from these experiences. Upon return to the US, students that registered for an additional course credit created video reflection presentations and wrote project proposal reports based on the needs identified in Ecuador. The project proposal reports were used to develop a BME senior capstone design project. Pre and post course self-assessment surveys showed significant increases in five ABET learning outcomes, three BME learning outcomes, and four course-specific learning outcomes. Students who took the two-credit course reported significant increases in four more learning outcomes than students who took the one-credit course. Many students described the experience as inspiring and life-changing, and the program continues to run each summer.

Keywords—Study abroad, Undergraduate, Design, Experiential learning, Service learning.

INTRODUCTION

Biomedical engineering (BME) students typically have a constrained schedule filled with specific course requirements, leaving little room for spending a semester studying abroad. Likely for these reasons, engineering students represent only 4.3–5.5% of US students studying abroad each academic year since 2013.11 Engineering programs around the US also encourage students to participate in international experiential learning through opportunities such as international co-op and internship placements and Engineers Without Borders projects,13 as well as summer research activities abroad.1, 9 Another option to work with student schedule constraints is to develop short-term study abroad courses that can satisfy technical elective course requirements.

Short-term study abroad experiences of less than two weeks are much less common than full-semester or summer term programs, but have increased in popularity in recent years.12 Past research on short-term study abroad experiences suggests students undergo change in their views and perceptions; come away with a better understanding of the host country’s economy and consumers; and the experience can influence stereotypes and misconceptions students may have about other nationalities.4 International engineering experiences present excellent opportunities for experiential learning and for service learning, typically defined as the combination of academic coursework with community service. Previous research has shown that participation in service learning courses correlated with more positive attitudes toward engineers’ social responsibility, and reflection activities for students during the experience may impact their attitudes toward social responsibility.5 Additionally, students who participated in service
learning indicated that service learning had a positive impact on their likelihood of continuing in engineering, that they were more motivated to learn and spend time on service learning projects, and improvement in teamwork and communication skills.6

Considering the benefits of short-term study abroad experiences and the combination of experiential and service learning, along with the interests of our students, Colorado State University developed a new 10-day BME study abroad course partnering with Range of Motion Project (ROMP), a non-profit healthcare organization that provides high-quality prosthetic care to underserved populations. ROMP has delivered over 3300 devices and completed over 9000 patient visits since its start in 2005, with clinics located in Guatemala, Ecuador, and the US.16 We also sought to increase the societal impact of this short-term study abroad course by developing year-long BME senior capstone design projects based on the needs identified throughout the study abroad experience in Ecuador. Finally, we aimed to address the common barriers to participation in study abroad: finances, academic fit, faculty and advisor support, fear, and friends/family.14

IMPLEMENTATION

Advising staff from Colorado State University School of BME connected with ROMP staff in summer 2017 to discuss potential collaboration. The idea to partner with the non-profit stemmed from student feedback during semester advising appointments with undergraduate BME students. Students shared that they were looking for practical engineering experiences, wanted to study abroad but were not sure how to fit it within their structured curriculum, and wanted to help others through a biomedical lens.

At that time, ROMP was offering an eight-day Ecuador Innovation Volunteer Program focused on user-centered design in a low-resource setting, based in their devLab and patient care clinic in Quito. These topics and the hands-on patient-focused nature of the program matched well with interests of many BME students, and we considered offering the international program as a non-credit volunteer experience or study abroad course for technical elective credit. In order to allow students to access financial aid, we decided to create a variable credit (one or two credits) short study abroad course. We also decided that the ideal time for the international experience would start about 1 week after spring semester finals end, with a return to the US before the end of May. This time frame gives students the opportunity to participate in other summer programs, internships, or jobs that often start at the beginning of June. This timing also allows students to develop viable senior capstone design proposals based on the experience in Ecuador over the remainder of the summer.

In 2018, the new Study Abroad: Prosthetics in Ecuador course was approved and 24 students (maximum capacity for this program due to clinical space constraints), representing six majors and 4 years of expected graduation, committed to participate. The second offering of the course, in 2019, enrolled 22 students with similarly varied academic experience. The vast majority of students were undergraduate BME majors (with a partner major of Chemical and Biological Engineering, Electrical Engineering, or Mechanical Engineering), but students from Health and Exercise Science, Biomedical Sciences, Chemical and Biological Engineering, and Mechanical Engineering also participated.

An Institutional Review Board exempt anonymous pre-course self-assessment including Likert-type 5-point scale responses regarding 20 student learning outcomes was conducted (n = 24 in year 1, n = 17 in year 2). Students were eligible to complete the self-assessments regardless of their major(s) and all responses were included in the analysis. The learning outcomes included ten Accreditation Board for Engineering and Technology (ABET) learning outcomes, four BME learning outcomes, and six program-specific learning outcomes. Throughout spring semester, six class pre-departure meetings were held to provide background on amputation and prosthetic care, ROMP’s mission, expectations in Quito, and to prepare students for traveling abroad.

About a week after the conclusion of spring semester, the students and two BME faculty/staff traveled to Ecuador. During the work week in Quito, the students participated in small hands-on teams with ROMP staff in patient evaluations, castings, fabrication of prosthetics, device fittings, rapid prototyping, testing iterations, and post-prosthesis gait training with physical therapy (Fig. 1). The students also worked with ROMP staff to explore potential future innovation for prosthesis production, such as applications of 3D printing and incorporation of recycled materials. ROMP staff provided “lunch and learn” sessions each day, and students, program leaders, and ROMP staff had dinner together each evening to allow for informal debriefing and exploring Quito. By the end of the work week, 16 patients were able to use their new prostheses, improving their mobility and quality of life. Weekends included guided cultural activities with ROMP staff, such as tours of historic Quito and Ciudad Mitad del Mundo, shopping at artisan markets, hiking to waterfalls and volcanoes, and staying at a hacienda and working farm. Each student maintained a journal with daily entries that reflected observations and in-
sights from these experiences. This journal and participation in daily activities comprised the two graded components of the course for students registered for one credit.

Students that registered for an additional course credit were also graded on their journal and participation in daily activities, and were also required to complete additional pre-departure reading assignments about recent advances in prosthetic technology. Upon return to the US, students that registered for two credits created video reflection presentations and wrote project proposal reports based on the needs identified in Quito. An anonymous post-course self-assessment of learning outcomes was also administered at this time \((n = 11 \text{ in year 1, } n = 10 \text{ in year 2})\), along with a program evaluation questionnaire from Colorado State University Education Abroad.

The student project proposal reports were used to develop a BME senior capstone design project. After the individual reports were graded, the instructor identified students that were interested in pursuing these projects in capstone, and encouraged these stu-
students to collaborate and combine elements of their individual project ideas. With support of the instructor, the resulting proposal was submitted to and funded by an entrepreneurial senior capstone design venture fund administered by the college. An interdisciplinary team of five BME seniors that participated in the study abroad course worked on this project, Sensor Technology for Enhanced Prosthesis Production, in academic year 2018–2019. The team developed a proof-of-concept prototype with preliminary validation results. With the project work completed under-budget, several team members returned to Quito after graduation to demonstrate their prototype for the ROMP team and receive feedback for further iteration. This capstone design project continued to be refined with a new student team in the following academic year.

**FINDINGS**

Student pre- and post-course assessment survey results were pooled for the 2 years of the program for statistical analysis. The results showed significant increases ($p < 0.05$) in five ABET learning outcomes (shown in Fig. 2): ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; ability to identify, formulate, and solve engineering problems; ability to understand the impact of engineering solutions in a global, economic, environmental, and societal context; ability to gain knowledge of contemporary issues (such as recent technology, regulatory and engineering standards, and intellectual property); and ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

These self-assessment survey results also showed significant increases in three BME learning outcomes (shown in Fig. 3): ability to solve BME problems, including those associated with the interaction between living and non-living systems; ability to analyze, model, design, and realize BME devices, systems, components, or processes; and ability to perform and interpret measurements on living systems.

Finally, the self-assessment survey results also showed significant increases in four course-specific learning outcomes (shown in Fig. 4): ability to understand the engineering design process; ability to understand the prototyping process; ability to understand the impact of resource-constrained environments on medical device design; and ability to understand the impact of incorporating user needs into design solutions. Although this course includes many elements about BME design, it is an addendum to the curriculum and is not intended to replace any existing curriculum requirements. Many students use the course to fulfill one or two credits of technical elective requirements for their degree.

These self-assessment results are supported by instructor assessments of the project plan reports ($n = 15$, assignment submitted only by students who took the course for two credits). Sections of the report assessment mapped to the following learning outcomes: ability to understand the impact of engineering solutions in a global, economic, environmental, and societal context (mean grade $\pm$ SD of 100.0% $\pm$ 0.0%); ability to gain knowledge of contemporary issues (such as recent technology, regulatory and engineering standards, and intellectual property) (mean grade $\pm$ SD of 93.7% $\pm$ 12.4%); ability to solve BME problems (mean grade $\pm$ SD of 96.0% $\pm$ 6.1%); and ability to understand the impact of resource-constrained environments on medical device design (mean grade $\pm$ SD of 90.7% $\pm$ 6.5%).

When the self-assessment survey results were compared between students who took the course for one credit versus two credits, students who took the two-credit course reported significant increases in four more learning outcomes than students who took the one-credit course (shown in Table 1). Interestingly, two learning outcomes that were not found to significantly increase student ability in the pooled analysis shown in Figs. 2, 3 and 4 were found to increase only for the students who took the two-credit course. These learning outcomes are: ability to function on multidisciplinary teams and ability to lead a group of your peers. This result suggests a higher level of engagement and leadership effort amongst students who were responsible for additional academic requirements related to the course.

The Education Abroad program evaluation questionnaire prompted students to write about the overall experience and personal reflection (representative responses to both prompts shown in Table 2). Responses to the overall experience prompt in the first offering of the course were very positive, but many students suggested that an additional day to extend cultural experiences would be appreciated, so the course was extended to ten days in its second and subsequent offerings. The personal reflection responses indicated many positive impacts, including motivation to continue in BME, to continue helping others, increased interest in the prosthetics field, and gratitude for a life-changing experience.

This short-term study abroad course also addresses obstacles to study abroad for engineering students. Others have suggested that universities need to acknowledge the “Five Fs of Study Abroad” (finances,
academic fit, faculty/advisor support, friends/family, and fear), and universities should work with students to overcome them if they want to increase study abroad participation. This study abroad course addresses the “Five Fs” in several ways. Regarding finances, the overall cost for this short-term study abroad is potentially less than a semester or year-long program (approximately $5000 for this short-term study abroad compared to around $18,000 for the average semester long study abroad, according to research by the International Institute of Education). Scholarships have also been created and distributed for high financial need students. As regards academic fit, many BME students are interested in the field of prosthetics and this study abroad course provides real life opportunities to explore those interests while
FIGURE 4. Course-specific learning outcomes that showed significant increases ($p < 0.05$) between pre- and post-course assessment (mean $\pm$ SE, $n = 41$ pre-course, $n = 21$ post-course).

| TABLE 1. Learning outcomes with significant increase in ability for students enrolled in 1-credit course compared to 2-credit course. |
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| 1 Credit ($n=23$ pre-course, $n=11$ post-course) | 2 Credits ($n = 16$ pre-course, $n = 10$ post-course) |
| Description of learning outcome | % Increase | Description of learning outcome | % Increase |
| Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability | 28.7 | Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability | 38.7 |
| Identify, formulate, and solve engineering problems | 22.7 | Function on multidisciplinary teams | 10.8 |
| Understand the impact of engineering solutions in a global, economic, environmental, and societal context | 25.5 | Understand the impact of engineering solutions in a global, economic, environmental, and societal context | 31.8 |
| Solve biomedical engineering problems, including those associated with the interaction between living and non-living systems | 28.7 | Solve biomedical engineering problems, including those associated with the interaction between living and non-living systems | 26.2 |
| Analyze, model, design and realize biomedical engineering devices, systems, components, or processes | 26.1 | Analyze, model, design and realize biomedical engineering devices, systems, components, or processes | 36.7 |
| Perform and interpret measurements on living systems | 39.6 | Lead a group of your peers | 15.1 |
| Understand the engineering design process | 19.3 | Understand the prototyping process | 43.7 |
| Understand the prototyping process | 26 | Understand the impact of incorporating user needs into design solutions | 35.4 |
| Understand the impact of resource-constrained environments on medical device design | 37.5 | Understand the impact of incorporating user needs into design solutions | 35.4 |
| Understand the impact of incorporating user needs into design solutions | 28.7 | Insight the prototyping process | 43.7 |
TABLE 2. Representative responses from a program evaluation questionnaire regarding overall experience and personal reflection.

**Overall Experience**

It was awesome!! I loved the program, the culture, the activities, the rain forest, and every minute that I got to spend in South America; however, I really think that this program could be just a little bit longer. I don’t know how much CSU has to do with the length of the program, but just one extra day would really make a difference. I loved this experience. I would’ve liked to be able to be there longer for a cultural experience as well as a clinical experience. I could see this program being great expanding into another week. But other than that the trip was amazing. We had a lot of hands on experience and an amazing itinerary to make sure we saw as much as possible. The physical activities were exhausting but they were meant to give us an appreciation for our mobility and making sure we don’t take it for granted. awesome. I would go back to Ecuador in a heartbeat and I have made lifelong friendships through this program. I will continue to try to stay involved with ROMP

This was one of the best experiences of my life. I was so worried because I am not an engineer major and I did not know anyone, but I met some amazing friends in such a short time. Ecuador was beautiful and I loved being immersed in the culture, walking to and from Fundacion Hermano Miguel, and going dancing with the interpreters. Being at the Fundacion Hermano Miguel was a life changing experience and has inspired me to work with amputees in my career field. 10/10 experience. Going to Quito, Ecuador is something I will never forget. I met people who chose a career where they are able to give people the ability to live a better life. To me there is nothing better that I can do in my lifetime than to do the same, and this trip gave me a glimpse of how it feels to do so. Learning the stories of the amputees and being able to witness them overcome their problems was absolutely an amazing and humbling feeling

This experience helped me personal figure out what career path I wanted to pursue. Full clinical observation from client fitting to delivery for the patient, but for me as well! Students motivated like that during difficult courses by seeing the impacts we can make with our future degrees. This experience really opened my eyes to limitations in healthcare worldwide, it was amazing to see the impact we made on these people’s lives but the conditions they were having to deal with in the first place caught my attention. Also, getting to meet all the people associated with ROMP and the fundacion was awesome, to talk with people who are so committed to helping others and changing their lives for the better is something I think anyone going into the healthcare industry should do, because it really motivates you to want to join them and have the same level of commitment. Lastly, being able to travel to a different country is always eye opening and an experience that change your life, for me it has now sparked a desire to look beyond the US in terms of healthcare: how can other countries obtain the same level of quality that is provide here

I feel like being a part of this program really ignited a fire in me to pursue working in underdeveloped countries on healthcare solutions. Illnesses, accidents, trauma, and disease do not discriminate, and thus healthcare shouldn’t either. I can’t wait to put my two degrees from CSU to very good use in the development engineering realm and help those less privileged than I. This program reanimated by excitement about my career options and about engineering as a whole, and I’m now much more excited to be graduating than I previously was!

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I was definitely impacted by the patients that we helped. They were so motivated and really made me reflect on what I thought my limits were. It turns out that I can actually do more than I thought I could

It was an amazing experience to see how the Heath care system and prosthetic care functioned outside of the States, it really changes your perspective on things. Personally I didn’t know if I wanted to choose a career path that involved prosthetics or not before this trip and after working with the patients and working hands on with the prosthetics I know for sure this is a career option for me now. This course allowed me to see what I could be potentially doing in my future with my degree and I think that it’s really important to keeping students motivated like that during difficult courses by seeing the impacts we can make with our future degrees

Being immersed in a different culture was amazing and having the chance to give someone their mobility back was not only life-changing for the patient, but for me as well!

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receiving academic credit in their program of study. Due to the length of the study abroad and time of the year offered, students are also able to participate in other academic opportunities over the summer such as internships. With respect to faculty/advisor support, due to the small faculty/staff to student ratio in this study abroad course, participants gain a closer experience with BME faculty and staff co-leaders, thus
building connections and rapport within the university community. In the long-term administration of this program, faculty and staff co-leaders rotate over the years providing more first-hand knowledge of the study abroad course, which is useful for information sharing during classes, advising appointments, office hours, etc. Faculty and staff co-leaders receive some supplemental financial compensation from the Office of International Programs from disbursed tuition revenue, and participate in this course in addition to their normal teaching/work load. As for friends/family, engineering is a team sport. This study abroad course offers a chance for students to have international experiences with their friends, make new friends, and may lessen the worry of parents/caregivers who are concerned with their student traveling abroad alone and for an extended period of time. Finally, concerning fear, studying abroad can seem intimidating especially for students who have never traveled outside the country. This short-term study abroad course offers the more timid student an opportunity to “dip their toes” into studying abroad and may contribute to further international exploration.

DISCUSSION AND CONCLUSION

Overall, the first two years of this short-term study abroad course suggest many positive impacts. Student pre- and post-course self-assessment surveys showed significant increases in five ABET learning outcomes, three BME learning outcomes, and four course-specific learning outcomes. Students who took the 2-credit course reported significant increases in four more learning outcomes than students who took the 1-credit course. These results are all based on student self-assessment, though they are partially supported by course assessments by the instructor. Student self-assessment is generally considered a useful proxy for indicators of student growth, though not a substitute for objective measures. Self-reported data likely relate with growth in attitude toward the subject matter, and not with cognitive performance. Therefore, one might conservatively interpret these self-reported results to gauge student perception and satisfaction regarding each learning outcome rather than a confirmation of proficiency for each learning outcome. Considering the importance of self-efficacy and professional role confidence in engineering major persistence, particularly for some historically underrepresented students, a growth in attitude or student perception related to the learning outcomes would suggest an important benefit from the study abroad experience.

Future data collection and analysis could further elucidate the impacts of this short study abroad course. Other potential impacts to explore include course assessments mapped to learning outcomes, assessment of intercultural competence and humility, assessment of the “Five Fs of Study Abroad” (both from students who participated in the program and those who did not), persistence in major, grades in BME courses, overall GPA, time to employment after graduation, and career and educational choices after graduation. As others have noted, student feedback regarding study abroad courses is generally extremely positive, but assessing the program and objectively measuring impacts of a broader perspective or more informed global awareness on professional development and career paths of participating students is challenging.

Finally, the ethical considerations of short-term study abroad programs with altruistic intentions and brief interventions must be examined, as there is potential risk for the experience to become an exploitative form of imperialistic intervention. Others with extensive experience facilitating study abroad experiences in developing countries suggest incorporating the following ethical pillars into programs: social justice and human rights, community capacity, dignity and worth of the person, self-determination, boundaries, competence, facilitative learning in a safe environment, and integrity. In this framework, the pillars support consciousness-raising as professionals and respectful engagement in context, resulting in higher levels of intercultural competence.

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All authors contributed to the course conception and design. Data collection and analysis were performed by EB-P. The first draft of the manuscript was
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Informed consent was obtained from all survey participants.

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