Improvement of an International Research Experience: Year Two

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Engineering Education. He has published more than 24 papers in reputed international and national journals on these subjects, presented 31 papers in various national & international conferences including held abroad and delivered many expert lecturers. Applied six patents and working on various funded research project. Did set-up an advanced manufacturing & mechatronics lab and supervised two PhD thesis & 10 ME dissertations. Passionate to work on product development and guide UG students on national & international competitions. He has mentored various student projects including at international levels namely "Human Powered Vehicle Challenge (HPVC) under ASME, MINI BAJA & Efficycle under SAEINDIA and Autodesk 3D CAD Design Challenge. An active member of IUCEE (Indo US Collaboration for Engineering Education), has taken many initiatives through Active Learning, PBL(Project Based Learning) and IOHC(Industry Oriented Hands on Courses) for effectiveness teaching-learning process.

Dr. Anil Kumar Jain MD DNB MNAMS, Dr. P.K. Sethi Rehabilitation Center, Santokba Durlabhji Memorial Hospital, Jaipur, India

Dr. Anil Kumar Jain

Anil Kumar Jain graduate (1988), Post graduate (1993) in Physical Medicine and Rehabilitation from SMS Medical College, Jaipur, India.

Worked with Dr. P.K. Sethi, Magsaysay 1981 and Rotary International Award winner 2001 (Jaipur foot innovator) in Research projects for Jaipur foot modification and low weight thermoplastic appliances for paralytic disorders, funded by Department of Science and Technology, Government of India (1996).

Qualified as Diplomat of National Board in PM&R in 1995.

Selected in Scientist Pool Scheme under CSIR, New Delhi Government of India (1996 to 1999).

Admitted as member National Academy of Medical Sciences (India) in 1998.

Remained involve in training doctors and technicians from Vietnam, Angola, Mozambique, Bangladesh for Jaipur Rehabilitation Technology.

Joined as assistant consultant under Dr. P.K. Sethi in 1999.

Head of the department since 2008 at Dr. P.K. Sethi Rehabilitation Center,SDMH, Jaipur.

Received young achiever's award by Jaipur Medical Association (2013).

Received "TIMES WELLNESS RAJASTHAN HEALTH AWARDS 2013" initiated by "Times of India".

JAIN BHUSHAN AWARD by Jain Social Group International Federation (JSGIF) in Rajkot, Gujarat on 29th March 2014.

Published articles and papers in international and national journals.

Delivered lectures on various topics in conferences organized by Orthopedic Association of SAARC countries (OASAC2014) Indian Association of Physical Medicine and Rehabilitation, Indian Orthopedic Association, Indian chapter of SICOT.

Selected for Jaipur belt-spinal brace project under US, India science and technology endowment fund (USISTEF), in association with Newndra Foundation, Jaipur and Paul Scott from Med Spark, California, USA.

Selected in 11 members International Advisory Panel to complete the systematic Review for International Society of Prosthetics & Orthotics (ISPO).

Dr. Tammy Lynn Haut Donahue, Colorado State University

Tammy Haut Donahue joined the faculty at Colorado State University (CSU) in December of 2011. She came to CSU after spending eleven years in Mechanical Engineering at Michigan Technological University. Her PhD was in Biomedical Engineering from the University of California at Davis where she earned the Allen Marr Award for distinguished dissertation in Biomedical Engineering in 2000. She is an Associate Editor for the Journal of Biomechanical Engineering and an Editorial Consultant for the Journal of Biomechanics. She is Chair of the Orthopaedic Research Society Meniscus Section, and is a member of the Bioengineering Executive Committee for the American Society of Mechanical Engineers. Dr. Haut Donahue's research includes analytical and experimental biomechanics of the musculoskeletal system with ongoing research in orthopedic biomechanics and post-traumatic osteoarthritis. An emphasis is put on prevention, treatment, and repair of injuries to the soft tissue structures of the knee, focusing primarily on the meniscus. With over $15 million in funding from Whitaker Foundation, CDMRP, NIH, NSF, as well as industrial sponsorship her research program has had more than 60 mentees and has national collaborations with Michigan State and Mayo Clinic as well as international collaborations with Trinity College Dublin and Queens University Belfast. Dr. Haut Donahue has more than 65 peer-reviewed publications and is current Associate Department Head for Undergraduate Studies for the Mechanical Engineering Department at CSU. Dr. Haut Donahue was awarded the Ferdinand P. Beer and E. Russell Johnson Jr. Outstanding New Mechanics Educator Award from the American Society of Engineering Education for exceptional contributions to mechanics education. Dr. Haut Donahue is a fellow of the American Society of Mechanical Engineers.

Improvement of an International Research Experience: Year Two

Six students from The Ohio State University were sent to Jaipur, India during the summer of 2015 to conduct research on the Jaipur Foot, a low cost lower limb prosthesis. As a continuation of the research conducted by the first cohort, in the summer of 2016 four different students were sent to Jaipur to conduct research. However, based on the successes and difficulties from the 2015 year, a number of changes were instituted to improve both the educational and research goals for the student researchers. This paper will outline these changes, identify how they affected student learning and technical success, and make suggestions for further improvement in the final year of the program. One major change to the structure of the research experience program included employing a research component to an independent study course during the spring 2016 semester. This course focused on preparing students from not only a cultural standpoint, but also from a technical content specific to the project, including the use of material testing systems and finite element analysis. As students from two geographically dispersed institutions were selected for the research experience, they were encouraged to adapt to working with both Indian and American scientists whom they had not previously collaborated with. The targeted improvements made in the second year allowed for better technical preparation and further development of collaborative and teamwork skills. These goals are evaluated using a broad range of metrics, including student journals during the research experience in India and pre and post surveys focusing on technical and teamwork skills specific to global competency. Observations suggest that students were better prepared to conduct technical research as a result of the expanded independent study course and that the limited interaction between students prior to arrival had no negative impacts on teamwork. This study could be used to support project specific technical education and preparing a diverse team prior to conducting undergraduate international research programs.

Introduction

With the advancement of the internet and transportation technology, our ability to positively impact the world we live in has greatly increased. This is particularly relevant for engineers, who often work on problems, solutions, and products which have direct global implications. Furthermore, engineering approaches vary based on geographical, economic, and societal factors [1]. To prepare engineering students for broad success, the development of global awareness is an important skillset [2,3]. Furthermore, international research experiences are a valuable opportunity for undergraduate students [4]. Previous international research experiences for undergraduate students have incorporated heavy technical preparatory work [5], limited prior training due to available time [6,7], and an introduction to cultural and technical content [8]. This work presents an approach to maximize student learning from a cultural perspective during a twelve-week international research experience. Specifically, students underwent technical and cultural training through an independent study program before traveling to Jaipur, India to partake in low-cost prosthesis research.

The Jaipur Foot is a low-cost prosthetic foot developed by Dr. P.K. Sethi in the 1970s in Jaipur, India [9,10]. The prosthesis was designed based on regionally available and inexpensive materials, and as such costs less than $15 to produce [9]. The foot has significant differences in structure, materials, and manufacturing process in comparison to other prosthetic feet such as the Solid-Anke-Cushioned-Heel (SACH). The Jaipur Foot is flesh-colored and shaped similar to a normal human foot, is waterproof, and is built to easily deform in dorsiflexion. These characteristics provide users with advantages specific to the Indian lifestyle over other prosthetic devices, including comfort in walking barefoot, squatting, and sitting cross legged. Additionally, the foot provides traction on uneven, wet, and rough terrain, allowing employed patients who require the prosthetic to continue a manual labor vocation.

The Jaipur Foot is comprised of locally sourced materials including wood, micro-cellular rubber, fiber-reinforced tire cord, and various rubbers including the external skin colored rubber. All materials used in the manufacturing process are environmentally friendly, with the exception of an ankle bolt and two nails [11]. Production involves applying an adhesive between the wood and micro-cellular rubber, wrapping the internal structure with reinforced tire cord and rubbers, and vulcanizing the whole structure [12]. The foot is currently produced entirely by hand and a skilled technician can produce several feet each day; however, there is little to no Quality Assurance, with large variations in properties due to the production process. This approach of using local materials and a production approach that relies on low-cost wages of the technicians allows the prosthesis to maintain an extremely low cost. However, the Jaipur Foot suffers from some major functional drawbacks due to its lack of design, material, and manufacturing standards. Specifically, the Jaipur Foot has a high apparent weight compared to a normal foot and an inconsistent lifespan due to a lack of standardization. Further, due to the need for technicians skilled in its production, the impact of the Jaipur Foot outside of India has been limited. The overall goal of this work is to provide a program for undergraduate students to develop broad engineering skills and global awareness while improving the functionality and manufacturability of the Jaipur Foot.

To address the design, failure, and material concerns of the prosthesis, various engineering and clinical techniques were utilized. These included tensile and compressive mechanical testing of the Jaipur Foot materials, finite element modeling of the prosthesis, and an epidemiological study of prosthesis failures. To prepare students for the development of global awareness in their designs, in addition to teamwork, communication, dissemination, and collaboration skills while abroad, a technical and cultural independent study program was developed and employed which focused on these skills [2, 6–8]. The belief in this approach was that students could gain knowledge of how biomedical materials behave and how to perform material testing and computational modeling prior to traveling abroad. This would promote more academic success, but also enable students to further develop technical writing once projects are completed, and spend more time collaborating with Indian scientists and clinicians as opposed to technical training.

Program Background and Approaches

This research experience program was a joint effort between The Ohio State University and Colorado State University. Four students were chosen based on academic record, a personal essay, relevant engineering experience, and a letter of recommendation. The four students were comprised of one female and three males, all at least sophomore academic standing, and in either Mechanical Engineering or Biomedical Engineering degree programs. Within the United States, technical and educational advising was provided by faculty and graduate students from both institutions. Indian advisors also provided support at both Santokba Durlabhji Memorial Hospital, where patients are fit with the prosthesis and at Malaviya National Institute of Technology Jaipur, a local research institution.

Students were selected Nov/Dec 2015 and enrolled in a one-credit independent study course Spring 2016. In comparison to the previous year where students were educated in cultural content only during the Spring, the 2016 course included four technical modules in addition to intermittent cultural content. These modules were as follows: 1) background research on the Jaipur Foot, 2) introduction to biomaterials, 3) experimental mechanical testing, and 4) finite element analysis. At the end of each module, students were asked to complete a report or project and provide either a written document, oral presentation, or both. Each module was three weeks in length, which was certainly a steep learning curve but allowed students at a minimum to become familiar with general language and approaches for these topics. Cultural differences between the United States and India, language introduction, pre-travel preparations (packing, likely weather, dietary differences) were included throughout the semester. While the students communicated via Skype during this course, there was limited collaboration between the two universities on assignments. This meant that upon arrival in India, students would have to adapt to working with Indian scientists and students whom they had never met, but also live and work with American peers they had not met. Thus, one question to consider is if the adaptation to new collaborators both nationally and internationally affected student performance.

To introduce the students to the Jaipur Foot from a societal, clinical, and engineering perspective, the first module was an open-ended assignment to research the history and details of the prosthesis. The students were given several peer-reviewed journal articles which provided general information on the Jaipur Foot, including historical background, materials, and manufacturing insight. Students were then asked to build upon these references with their own literature search and prepare both a written report (less than ten pages) and an oral presentation on the Jaipur Foot. Each group presented over Skype, submitted their written report, and shared differences in information gathered. Information from this module included the health and societal impact of the Foot, materials, and structure.

The second module applied a similar approach to the first module, with a focus on biomaterials. The goal of this module was to give the students an introduction to how biomedical materials behave differently from traditional engineering materials such as metals and ceramics. Again students were asked to prepare oral and written presentations and share them with the group. Topics from this section included nonlinear (hyperelastic), anisotropic, and time dependent (viscoelastic) material behavior in addition to the effect of vulcanization. This module introduced students to the notion that the materials they would be working with are vastly different than many of the materials typically studied as an undergraduate in engineering, such as steel and aluminum. Armed with the knowledge of these first two modules, students gained important insight into the structure-function relationship of the Jaipur Foot, answering the question "How is the Jaipur foot built and how does it behave?"

The third and fourth modules were specific technical skills commonly used in biomedical and mechanical engineering – material testing and finite element analysis – that were particularly relevant to studying the Jaipur Foot. The material testing module focused on performing the general protocol required to obtain, test, and analyze experimental samples using hydraulic testing equipment. This included specimen machining, both tensile and compressive material testing, application of a pre-load to a specimen, selection and use of load cells, and various testing protocols. This module was specifically designed to provide general approaches for all material testing systems, enabling students to use the skills they developed on different systems and models. Additionally, students were exposed to testing and characterization of nonlinear and anisotropic materials which most had not seen before. The final project from this module was a presentation of material characterization for materials used in the Jaipur Foot.

The fourth and final module led students through the development and analysis of increasingly complex finite element models. Included in this section were geometry definition, mesh development and the role of mesh density, material properties definition (including nonlinear and anisotropic materials), contact, step definition, and output analysis focusing primarily on stress and strain. The overall goal of this module was to prepare students to either further develop their computational capabilities by developing a finite element model of the Jaipur Foot or to be able to place modeling results into context. To complete the module, students developed and analyzed a model of a sphere indenting a cylinder, which is a classic nonlinear finite element solution to a contact problem.

Upon completion of the independent study course, students travelled to Jaipur, India to perform research on the Jaipur Foot focusing on three distinct projects: 1) an epidemiological study of Jaipur Foot failures, 2) evaluation of mechanical properties of the materials used in fabrication, and 3) the development of a finite element model of the Jaipur Foot. While in India, students were in contact with all advisors from the United States on a weekly basis through Skype. Student housing was located at SDMH, which provided direct insight into the clinical process of fitting the Jaipur Foot to a patient. Research endeavors were performed typically at MNIT, which is home to a wide range of fabrication and analysis equipment. Upon arrival in India, students were housed in a single apartment for the twelve-week research experience.

From an evaluative standpoint, students were given a survey both pre and post travel, which included questions on their perception of their global aptitude (or awareness) and how well prepared the students felt from a cultural and technical standpoint (post survey only) (Table 1). A Likert scale was used as follows: “Strongly disagree” (1), “Somewhat disagree” (2), “Neither agree nor disagree” (3), “Somewhat agree” (4), “Strongly agree” (5). Students also completed journal entries approximately twice a week reflecting on their cultural experiences, technical and research progress, and any other topics they found important. These journals acted as a method to reflect on all experiences while abroad without discussing with peers, including research successes and struggles, cultural experiences, and personal viewpoints. Additionally, exit interviews were also conducted upon arrival back in the United States. These exit interviews acted as a method to gauge interest in completion and/or dissemination of research conducted while abroad, discuss possible areas of further improvement, and to provide students with an opportunity to reflect on their experience. Three of the four students continued to work on dissemination of technical research findings, with the end goal of producing a peer-reviewed publication.

Table 1. Pre and post survey question numbers and question content.

Number	Question Content
1 - Global	I am capable of working as a global technical professional.
2 - Global	I am aware of regional variations in technical standards, code, etc.
3 - Global	I can make ethical decisions in the context of a different culture.
4 - Global	I am familiar with cultural differences in professional ethics.
5 - Global	I understand how my technical perspective is different from those in other regions.
6 - Global	I am prepared to work with people who define and solve problems differently.
7 - Global	I am aware of how culture influences technical work.
8 - Global	I can adapt my technical knowledge and skills to different local conditions.
9 - Global	I can coordinate technical work that spans multiple countries.

10 - Global	I can function effectively as a member of multinational/cultural technical teams.
11 - Global	I can communicate professionally in a culturally-appropriate manner.
12 - Global	I am prepared to work with professionally from cultures different from my own.
1 - Prep	I found the independent study course helpful.
2 - Prep	The meetings with [Indian collaborators] were helpful.
3 - Prep	I felt prepared for the trip based on knowledge of Indian culture.
4 - Prep	The discussions on what to expect and pack covered my questions.
5 - Prep	I felt I needed more preparation about the culture/food, etc.
6 - Prep	I found the biomaterials literature review helpful.
7 - Prep	I found the material property assignment helpful.
8 - Prep	I found the finite element modeling assignment helpful.

Findings

Students reported high confidence in their ability to function globally as engineers after the program (Figure 1). For each of these twelve global awareness questions, the average student confidence increased between the pre and post surveys. While none of the individual global questions had a statistical increase from the pre to post survey likely due to lack of power, the compiled responses for all twelve global competency questions increased significantly ($p=0.0001$) according to a nonparametric Mann-Whitney test. This is similar to data from the previous year, where students all reported similarly high levels of global competency. The development of globally cooperative skills was noted by one student journal entry in regards to working across cultural and language boundaries from a technical perspective:

> "Working on a project in a different country has definitely giving me insight on how working internationally functions, where everyone isn't used to working the same way as you. I think it's an important lesson to be able to adapt to your environment and continue on."

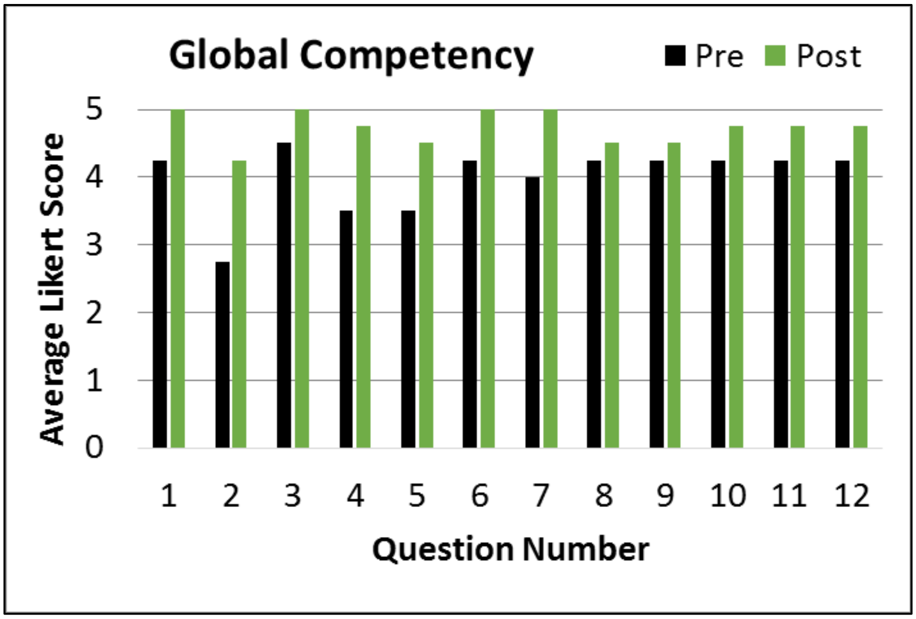

Figure 1. Average Likert scores from the pre and post surveys for global competency questions.

In general, students also felt very well prepared to immerse themselves in the Indian culture (Figure 2 questions 1-5). One observation, however, is that students felt they needed more insight into dietary and specific cultural differences (Figure 2 question 5, average Likert score of 2.5). This was somewhat by design in encouraging students to further learn the cultural differences between the United States and India while abroad. As such, it is not surprising that the students felt they could have used more preparation from a cultural perspective. Variability in dietary success while in India, which was achieved by some students through trial and error, could have also contributed to this specific response.

From a technical standpoint (Figure 2, questions 1-2, 6-8), the independent study program was well received in terms of student preparation. Both the biomaterials and material testing modules (Figure 2, questions 6-7) showed high Likert scores (average of 4.25 and 4.5, respectively). While the finite element module had a slightly lower score (Figure 2, question 8, average Likert score of 3.75), this may have been due to changes in specific finite element software while abroad and availability of specific software in India versus the United States.

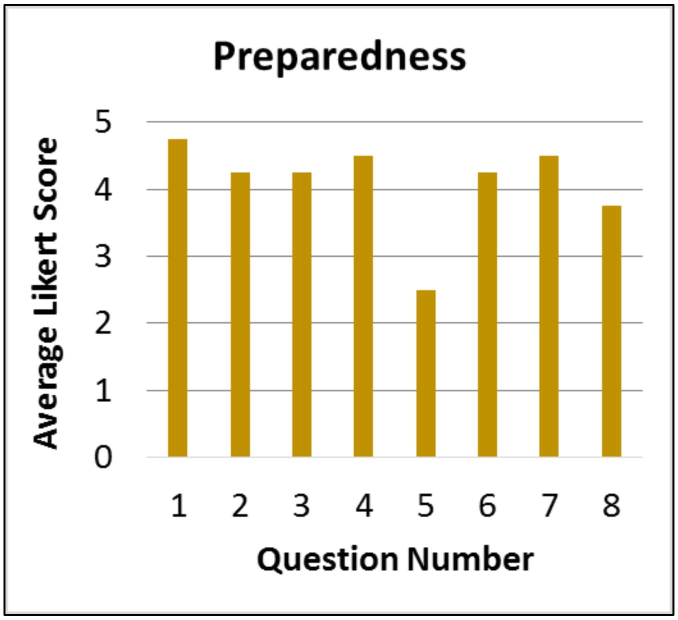

Figure 2. Average Likert scores from the post survey for questions related to student preparedness.

Overall, the circumstance of meeting, living, and working with new peers in an international setting did not seem to cause personal or professional issues during the program. While it is difficult to make strong conclusions from such a small sample size (four students), variability in personality, career interests, and experiences may have contributed to this success. While minor disagreements were encountered, respectful communication prevented any major issues. As part of the independent study course in the Spring, conflict resolution and teamwork was a topic that was covered to aid with this interaction between the students. As noted by one student, the initial meeting went well and successful teamwork continued throughout the summer:

> "I like my fellow interns so far. We all get along very well and I do not foresee any problems living and working with them for the remainder of the summer."

From a research standpoint, students focused on three independent projects while in India and upon returning to the United States: 1) an epidemiological study of the Jaipur Foot, 2) a summary of the mechanical properties of the materials used in the prosthesis, and 3) a finite element model of the prosthesis. These three projects are either in the dissemination and submission phase for peer-reviewed journals or are in the data analysis phase. Thus, from a research standpoint, this program was a success. While this is certainly a contribution of a multitude of factors, including previous years' research, targeted approaches, and effective teamwork, a major contributor was likely the role of the independent study course. The prior year, for example, yielded important foundational data on the Jaipur Foot materials and research methods, but did not produce peer-reviewed published work. In the case of material testing, students were able to generate their own testing matrix, fabricate specimens, and employ specific testing approaches in India without the need for additional training. From a finite element perspective, understanding mesh density and boundary conditions significantly reduced the learning curve.

Discussion

The broad goals of this international undergraduate research experience include providing undergraduate students with technical research skills, soft skills, global awareness skills, and an opportunity to perform meaningful research on a low-cost prosthetic limb, the Jaipur Foot. To better achieve these goals, an independent study program was employed which provided both technical and cultural preparation prior to travel. While year two students observed similar increases in global competency as year one students, the development of technical skills and the significant success of published research are likely due in part to employing this independent study course. Specifically, while year one yielded a meaningful experience for students and valuable research data, it did not produce technical peer-reviewed content. Year two, however, yielded three manuscripts which are either in submission or production phase. Thus, it is likely that greater exposure to technical content prior to travel better prepared students to conduct research, while still allowing them to experience an impactful cultural opportunity.

It is important to note that the semester independent study was a 1 credit course over 15 weeks with only 1 contact hour per week between instructor and student, while the time in Jaipur, India was 10 weeks, with 40 hours a week of dedication to the project. Thus, it is not surprising that students achieved excellent global awareness at the completion of the program (Figure 1). The inherent difficulty in teaching students meaningful content on the advanced approaches and topics of biomaterials, material testing, and finite element analysis within a short time frame could leave some students feeling as though they could have received more preparation to conduct research in these areas (Figure 2). One potential area for improvement would be to create a 3-credit technical elective course for the students to take instead of a 1 credit independent study.

While the independent study approach was effective, there remains room for improvement. Specifically, there is the opportunity to utilize prior research endeavors as educational opportunities. In the case of finite element analysis, if geometry and meshing has already been completed, the specific finite element model of the Jaipur Foot could be used as an example to teach the module. Students would thus be familiar with both general finite element approaches as well as the specific project. Future implementation of the course could also include more emphasis on dealing with setbacks and how technical troubleshooting varies between the United States and India. Student journals are a valuable source of this information, as one student noted these challenges:

> "Coming into this internship I hadn't anticipated some of the obstacles we were going to face, such as the protocols for running some of the equipment, or the time it would take to get additional materials and vulcanize them."

The challenges students faced; however, should not be viewed in a negative light. Student growth is tied to students having some control over their educational environment [14]. Thus, while there is always the opportunity to better prepare students to succeed, an important aspect of the success of this program is not preparing students for each outcome but providing them with the skills to encounter new difficulties and determine solutions independently. The purpose of the international research experience is, after all, to place them in an environment where they will be challenged, learn technical engineering skills, and to gain an invaluable global skillset.

Conclusions

In summary, this work presents an approach to an international research experience for undergraduate students which involved an independent study course prior to travel. This course utilized a modular approach to provide students with 4 major technical skillsets to succeed in research while in Jaipur; background on the Jaipur Foot, biomaterials, material testing, and finite element analysis. Additionally, intermittent content on cultural differences between the United States and India, pre-travel preparation, and soft skills such as teamwork and communication, were included. Students found the independent study course prepared them well from a cultural and technical standpoint, facilitated their development of global awareness skills, and resulted in research manuscripts for submission in peer-reviewed journals. This approach could be a useful model when incorporating international research projects into an undergraduate education. Overall, this program provided an international research experience for undergraduate students, as summarized by one particularly poignant journal entry:

> "If I had to guess at the learning goals set for us by our organizing professors, I would expect that a major one would be that we learn what kind of real-life obstacles to expect in research. If I'm correct, I'd say that that goal has certainly been achieved …"

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