International Senior Design for Mechanical Engineering Students

T. H. Donahue
Associate Professor
Colorado State University
Fort Collins, Colorado, USA
E-mail: tammy.donahue@colostate.edu

S. A. Sorby[1]
Visiting Professor
The Ohio State University
Columbus, Ohio, USA
E-mail: sorby.1@osu.edu

A. Campbell
Undergraduate Student
The Ohio State University
Columbus, OH, USA

Conference Key Areas: Inclusive design education, Internationalisation

Keywords: Design education, Humanitarian engineering, Women in Engineering

Introduction

In September of 2009, the decision was made to offer a new type of design project, a project with a humanitarian focus and an international component, for senior mechanical engineering students. The new international design program would include a project centered on the design of assistive devices for handicapped children in India. India, the second most populated country in the world, representing about one sixth of the world's total population, has approximately two thirds of its population living in poverty. India has the largest concentration of poor in the world with forty-two percent of Indian citizens living below the World Bank's International Poverty Line of making US$1.25 or less per day. Many live without even the basic necessities of western culture, such as clean water and weatherproof shelter. Due to living conditions, home birth, and lack of vaccinations, the incidence of polio, spina bifida, cerebral palsy, and other spastic conditions remains high in low and no income families in India. Eighty percent of cerebral palsy is spastic, in which most of those affected suffer from one to two lower limbs being affected. Those lower limbs that are affected are weak, and the ability to walk without an assistive device is

[1] Corresponding Author
SA Sorby
sorby.1@osu.edu

challenging. Furthermore, India is one of four countries in the world that has not eradicated polio. In about one percent of the cases of polio, the virus will enter the central nervous system and destroy motor neurons leading to muscle weakness and acute flaccid paralysis (AFP). Spina bifida, a developmental birth defect, leads to the weakening of lower limbs depending upon which part of the spine is affected. Clearly, there is a dire need for low-cost assistive devices in India.

That being the global problem of interest, there is a local problem of interest as well. Engineers often lack international experience and the ability to think globally. The curriculum is typically too "full" to enable study abroad experiences or to allow for in-depth study of other cultures. The lack of a global focus in the undergraduate curricula is to the detriment of the field in that engineers typically work in global companies and are required to interact with colleagues from across the world. The proposed initiative addressed this through having teams of engineering students at Michigan Technological University design, prototype, and develop low-cost assistive devices that meet the constraints of Indian culture while meeting the processes, tools and skills constraints associated with the target Indian workforce. This project represents the type of situated learning experience advocated by Lave & Wenger (1990) where students solve problems in the culture and context where they occur. Brown, Collins & Duguid (1989) further theorize about the concept of cognitive apprenticeship where students develop cognitive tools in an authentic setting.

In April 2010, to prepare for this international senior design option, two faculty from the Mechanical Engineering Department (Dr. Haut Donahue and Dr. Sorby) visited the New Delhi area to learn about problems with currently available assistive devices in India and to make contact with local healthcare providers in order to establish design goals for the assistive devices. The Michigan Tech Team visited the All India Institute of Medical Sciences (AIIMS), a comprehensive institute for teaching, research and patient care. Dr. Rajesh Malhotra, Professor of Orthopaedics and his team provided us with patient information and problems currently faced by children in India related to mobility/ambulation. Together, the need for a low-cost, low-energy consuming reciprocating gait orthosis (RGO) device that would suit the Indian culture was identified. Additionally the Michigan Tech Team visited Ms. Neena Macedo, President of the Delhi Council for Child Welfare (DCCW). Here more than 15 pediatric patients were identified and interviewed. The need for a low-cost caliper system to allow these children to better live in the Indian culture was identified. In addition, Drs. Donahue and Sorby visited with Dr. Anil Jain to discuss the innovative Jaipur Foot (described below). Several design criteria were dictated by patient health needs as well as societal and cultural aspects of living a handicapped lifestyle in India.

Figure 1.A) traditional position for prayer for Indian culture. B) common position of squatting for Indian lifestyle.

The living conditions in India give rise to disabilities, including polio, that are either not seen or not prevalent in the US. Diseases such as club foot are treated very early if they occur in the US whereas in India the doctors often see patients very late and the diseases have progressed, presenting drastically different health challenges than seen in the US. With over 2/3rds of the India population living at or below poverty levels, the cost of health care and treatment options must be inexpensive. The Indian culture is one in which prayer is very important. Sitting cross-legged (Figure 1A) during prayer is something current gait assistive devices do not permit, yet traditional culture calls for. Additionally, Indian culture includes squatting for short and long periods of time (Figure 1B). When citizens are not lying down or walking, they sit cross-legged or squat for comfort. Most of the toilet facilities available in India are holes in the ground or fields in which squatting is essential to be able to go to the bathroom. Currently available assistive devices do not allow these positions to be attained. By producing a design that is user friendly, allowing the wearer to participate in the day-to-day cultural activities of his or her people, while maintaining low-cost affordability, this initiative aims to fill a niche of human need that has been ignored for decades.

Jaipur Foot

The incidence of missing limbs, particularly feet/legs, is much higher in the developing world, when compared to the U.S. There are several factors that contribute to this phenomenon. First, health care is not as readily available in the developing world meaning that simple infections may lead to amputations at an alarming rate. Second, the farming implements used in developing countries are relatively primitive and can lead to mishaps and severed limbs at a much higher rate compared to the U.S. Finally, in many of the poorest regions of the world, there are residual land mines left over from recent or even long past conflicts. For example, in the United States around 1/22,000 people are amputees whereas in Cambodia it is 1/256 people, in Somalia it is 1/1000, and in India it is 1/56 (Pickhart). As of 2001 there were 25 million disabled people in India and 75% of them are living in rural areas, 49% are literate, and 34% are unemployed (Adalauasu, Jagannath, and Mathur).

Prosthetic devices in the western world have made significant advances in the past fifty years. In fact, in the summer 2012 Olympic games, a double amputee was able to realistically compete with whole-bodied individuals in running events. Unfortunately, these devices are out of reach of the world's poor. Not only are modern prosthetics prohibitively expensive for the average farm worker in the developing world, but also the complexity of the devices requires custom fitting and "retraining" in the mechanics of ambulating. Most of the world's poor can not spend that much time away from their work, if they are to be able to feed and support themselves and their families.

Recognizing the need for a low-cost, simple prosthetic device, Dr. P.K. Sethi of the Rehabilitation & Jaipur Limb Training Centre in Jaipur, India developed a low-cost simple prosthetic device known as the Jaipur Foot in the 1970s (it should be noted that the Centre now bears the name of Dr. Sethi). When Dr. Sethi first started to look to improve prosthetic feet, he kept observing that when people were using a wooden prosthetic foot, they would get cracks along the grain and where the wood attached to the bolt, so he deduced that these feet were not holding up to the normal stresses that people in India put on them every day (Sethi, Udawat, Kasliwal, and Chandra). After much consideration and testing, it was theorized that a sponge could be put into the foot in different layers, with the layers glued together to form the foundation of the foot. This would allow for more free movement and would cut down on the breakages because the sponge material is much more flexible than wood (Sethi, Udawat, Kasliwal, and Chandra).

After much trial and error testing in the development of the foot that included the sponge foundation, a study was conducted on the foot and they found that when the foot was vulcanized and heated to high temperatures the glue was actually giving way. Based on these results researches went to find a heat proof adhesive but as people kept on wearing these prosthetic feet and they found that the glue giving way was what made the foot so movable. The separated layers were now able to glide over each other leading to an even greater level of mobility than the creators planned (Sethi, Udawat, Kasliwal, and Chandra). After the sponge is shaped the foot is then covered in a hard rubber that is about 2 mm thick to allow people to walk barefoot. The rubber is also waterproof and is skin colored so it is acceptable to wear the prosthetic foot barefoot and it looks as close to normal as one could get with a prosthetic foot (Sethi, Udawat, Kasliwal, and Chandra). The sole is made of the rubber that is commonly used in car tires and is known as rubber tread compound. The sole is a heavier and stiffer rubber than on the rest of the foot because it protects this highly used part of the foot (Sethi, Udawat, Kasliwal, and Chandra). This rubber allows greater resistance to abrasion, tears, and cuts than the other rubbers in the foot. Figure 2 shows the Jaipur Foot in action.

Figure 2. Jaipur Foot in Action (http://jaipur.cc/Jaipur_Foot.htm)

Projects

The International Senior design option in Mechanical Engineering has been offered for a total of three times, in 2010-11, 2011-12 and in 2012-13. In each year, two student teams tackled separate projects for clients in India. In the first year of the initiative, the projects included a knee-ankle-foot-orthosis (KAFO) device to meet the needs of local New Delhi children with gait affecting disorders such as polio and cerebral palsy. The team strove to create a KAFO that would not inhibit a child's daily activities with range of motion that allows the wearer to sit cross-legged and to squat down, while increasing comfort and decreasing cost. The team's design used a spring-action hinge to decrease the amount of effort needed to unlock the brace while still locking itself in place when the knee is straightened. By decreasing the weight and maximizing the durability of the product, the design was intended to give the children who use it an improved wearing experience for a longer duration. The second team designed a Reciprocating Gait Orthosis (RGO) device to aid in ambulation for children who suffer from cerebral palsy, polio, or spinal bifida. An RGO consists of braces for each of the legs that attach at the hip and incorporate some means for aided forward propulsion. The major goals of this project were to make an RGO that was significantly less expensive than products that are currently available and to enable users of the RGO to take part in normal daily activities such as squatting all while ensuring the device was low-energy consuming. Both teams were given design constraints/criteria that required their product to be innovative in order to significantly improve on what is currently available in India and the devices needed to be made from materials and tools available locally in New Delhi. While these products are available in both US and India, they currently do not have enough range of motion in the knee to allow sitting cross-legged and squatting and they are too expensive.

In the second year of the program, the two projects chosen by senior design leaders at Michigan Tech were the design of a low-cost artificial knee that could be easily fabricated in India at a fraction of the cost of commercially available knee. The second team attempted a revised design of the Jaipur Foot to make it lighter without sacrificing durability. And in the third year of the program, teams essentially continued on with these projects—making the artificial knee joint even lighter and more functional and making further improvements to the Jaipur Foot.

Implementation

The international senior design option was implemented beginning in the 2010-11 academic year. In each year, students in MEEM 4901-Senior Capstone Design were given a list of 30 different projects, two of which were International Senior Design projects. Each student was asked to list their top 3 choices and to provide a resume. In the first year, eight (1 female and 7 males) students were selected to participate in the 2 international projects, with 4 students on each team. In the second year of the program, there were two teams of six students each (eight females and four males) and in the third year there were nine students (six males and 3 females). Each team was assigned a faculty advisor in the Mechanical Engineering Department. The students' first points of contact were Dr. Haut Donahue and Dr. Sorby who were sponsors of the projects. After initial meetings to define the design constraints, the students were encouraged to contact their respective sponsors in India.

Michigan Tech's Mechanical Engineering (ME) Senior Capstone Design (SCD) project is required for all students. The students in the International Design course followed the normal outline for the Senior Capstone Design course. Prior to enrolling in the year-long SCD course the students completed a 3-credit junior-level course that introduces the engineering design process; topics include thinking styles, teamwork, creative problem solving, brainstorming, Pugh method, technical report preparation, economic decision making, quality, analytical and experimental design optimization, DFA, DFM, GD&T, codes and fasteners, robust engineering, engineering ethics, patents and IP, and innovation in the workplace. Following this introduction to design, they enrol in the 2-semester SCD course sequence, where they work in teams on "open-ended" engineering design projects developing original and creative solutions to real engineering problems.

Cultural and social barriers. None of the Michigan Tech faculty or students currently involved speak Hindi. However, both Dr. Malhotra and Ms. Macedo, the two primary members of the India Team, speak fluent English. During our initial recruiting trip in April 2010 both Dr. Malhotra and Ms. Macedo translated for the Michigan Tech Team so we could talk to patients and employees at the facilities we visited. Part of the experience for the Michigan Tech students was to understand that the design challenges associated with this initiative would not exist if the children lived in the US.

A specific example of a culturally derived technical constraints in these initial design projects is that the devices must provide a large range of motion (~120°) so that squatting and sitting cross-legged are possible; two positions critically important in Indian culture. This would be of minimal engineering importance under the US healthcare and health insurance system, but quite the opposite to achieve this functionality at the low-cost that is critical in the Indian market. These problems are unique to Indian culture; thus, properly defining the objectives and constraints (as done by a completing team during their concluding delivery and project development visit) relies upon truly understanding the culture. To facilitate this understanding, we planned activities for the Michigan Tech group throughout the year while they worked in the US. This included presentations by Michigan Tech Indian faculty and their spouses, regarding lifestyle, history, religion, and culture. We also had the students watch movies such as Namesake, and Slumdog Millionaire to gain an appreciation for Indian culture. Additionally, all senior design projects require regular group meeting with advisors and sponsors. Milestones were set throughout the 2 semester course so that there would be a working prototype at the end of the year.

The projects culminated in a faculty-led student trip to India to test the devices and to identify projects for the following year. The trip was set up to include meetings and delivery to each location, identifying projects at current locations and new locations, free “tourist” time, and follow-up visits were all part of the experience. The duration of each trip has been ten- eleven days, including two travel days at the beginning and one travel day at the end. In the first year, we travelled to India at the end of the academic year, immediately after graduation. In the second and third years of the program, the trips were made over the students’ spring break at the beginning of March. For each trip, we have interspersed tourist activities (the Golden Triangle) with meetings with project clients. Students experienced an elephant ride at the Amer Fort in Jaipur as well as a tour of the Moghul wonder of Taj Mahal.

Financial Plan

In these times of declining resources, implementing a program such as this needs to be accomplished with minimal financial input from the institution. Unfortunately, this means that the brunt of the cost of the program will necessarily be borne by the students. The Mechanical Engineering Department at Michigan Tech supported the cost of materials to build the design prototypes that were delivered to India. Each student who enrolled in International Senior Design was assessed a course fee that was significantly higher than students enrolled in the standard Capstone Design course. This course fee was then used to pay for ground transportation, lodging and food while in India. This fee also offset the travel costs of the two faculty who accompanied the students on the trip to deliver the projects.

Challenges and Benefits

Challenges: The international component of these projects provided a unique set of challenges to the senior students beyond the expected traditional course-related design challenges. Practically there was a 9.5 hr time difference which needed to be overcome for meetings with the India contacts. Video conferencing, email and conference calls were the most heavily used means of communication. While the Indian contacts spoke English, there were still challenges for the students to convey their ideas and interact with a different culture. Additionally the students were required to ensure all parts used in the devices were readily available in India.

Benefits: During the delivery visit, the students were given the unique opportunity to identify design projects for the following year of students. This required the students to identify potential contacts, meet with them, understand the problems/challenges and identify design constraints. The only requirement was that the design projects (market opportunities) identified are for assistive devices aimed at helping those living in poverty. From an academic perspective, this final task brought the global experience full circle.

Assessment

During the first year of the program, while on the trip to India with the students, we posed 9 questions to the students to assess their overall experience and improve upon the process. The questions, a summary of their responses, and representative comments are included in Table 1.

Table 1. Assessment Questions and Responses

Question	Summary	Representative comments
Should we do this again?	All students said yes	1) This was an incredibly worthwhile experience, both culturally and educationally. The chance to help others through engineering is the purpose for me choosing engineering. 2) This was far and away the most incredible and valuable experience of my undergraduate career.
Please provide comments regarding the timing of the trip	Mixed results. Most thought the end of the year was the right time to do this.	1) Thanksgiving, the earlier the better to better understand the culture and project objectives and constraints. 2) The timing was great. Having it at the end of the year also gave us something to work and look forward to.
Please comment on the length of the trip	All students responded 8-10 days	
Please comment on the balance between work and tourist activities	All students thought the balance was excellent	
What are some things we should have told you but we didn't?	How spicy the food was and about bargaining/hawkers	
What things should we keep the same?	The break in the middle for tourist activities.	

What things should we change?	A variety of answers	1) Set up the first teleconference or try and bring them to Michigan Tech. 2) Help students pay for trip. 3) Have a meeting close to departure 4) I'd like to see some ancient Indian sites as well as more recent Moghul ones. 5) More time to go off on our own. Time to relax.
What would you tell other students thinking about this?	A variety of answers	1)This presents a great opportunity to expand you culture diversity. Also, working on these projects will really open your eyes on how nice we have it; don't take things for granted. 2)This is a life-changing experience, something that has to be seen, touched, smelled to be understood. As far as projects go, tell students to get in direct contact with their collaborators from the start.
Why did you choose this project?	A variety of answers	1) It was one of the few that didn't deal with engines. It also had a great impact on the people it was for. I couldn't pass up the opportunity to travel to India. 2) This project was my first pick because it had direct application of mechanical engineering concepts while benefitting humans in a visible way. 3) I really wanted to do a project that let me use my knowledge of engineering to make a meaningful contribution to people who don't have all the benefits of life I do. I have long been fascinated by India, and the opportunity to help Indian people with my education was entirely fulfilling.

Conclusions

The International Senior Design offered through the Mechanical Engineering Department at Michigan Tech has been a success by all measures. The sponsors in India have been happy with the projects overall and the students felt they gained global experiences through choosing these projects and making the trip to India. As this project moves forward, the details of the trip need to be revised. The students felt that an early trip to better understand logistics would have been beneficial, but none wanted to give up the trip at the end of deliver the prototypes. Thus, a unique solution must be found to better equip the students with information at the beginning of the project. Overall the experience was found to be valuable to the students and will continue in the future.

ACKNOWLEDGMENTS

The authors would like to acknowledge financial support from the Mechanical Engineering Department at Michigan Tech.

REFERENCES

[1]. Brown, J.S., Collins, A. & Duguid, S. (1989). Situated cognition and the culture of learning. Educational Researcher, 18(1), 32-42

[2]. Lave, J., & Wenger, E. (1990). Situated Learning: Legitimate Peripheral Participation. Cambridge, UK, Cambridge University Press.

[3]. Sethi, P. K., M. P. Udawat, S. C. Kasliwal, and R. Chandra. "Vulcanized Rubber Foot for Lower Limb Amputees." *Prosthetics and Orthotics International* 2 (1978): 125-36. *Prosthetics and Orthotics International*. Web. 6 May 2012. <http://www.oandplibrary.org/poi/pdf/1978_03_125.pdf>.