

International Engineering Education: A Case Study of Working in Low-income Countries

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Abstract

International engineering education is becoming a topic of continued interest and focus, especially at US institutions. Yet the means by which these institutions seek to provide an international education are extremely varied. We discuss our efforts at using an ongoing international program, LEGS, which aids amputees in low-income countries with improved prosthesis technology. We also focus on how LEGS is used to educate students in engineering design, cultural competencies, interdisciplinary work, among many other ABET outcomes. We have found that working in foreign cultures with various other professional disciplines enhances the educational outcomes which are becoming increasingly needed in our ever changing world, especially as we become a more interconnected global community which now includes the developing world. Yet, challenges in seeking to use international aid programs as educational mechanisms come with considerable costs. These costs must fully evaluated and seen in light of the educational outcomes of the institution. That is, balancing the needs of the end-user along with educational outcomes is a juggling act that can easily overwhelm a project. Nonetheless, if project demands are properly addressed, student engineering education outcomes are strongly reinforced in the context of students applying engineering skills to aid the poorest of the poor. In our experience, this results in one of the most profitable student educational experiences – a life changing experience.

Need for International Learning

In an address to the Institute for International Education Colin Powell stated, “The challenges we face in areas such as security, democratic development, economics, and health cannot be addressed by any country acting alone. International education -- learning about other cultures and languages through study, living overseas, and interacting with people of other countries -- promotes the free exchange of ideas, allows us to seek joint solutions to problems, and helps create lasting partnerships to meet our shared concerns”[1].

While the number of U.S. students studying abroad is increasing, that increase is not evident across all academic disciplines. The annual report by the Institute of International Education states that 40.1% of the undergraduate students studying abroad were social science or business majors. Only 2.7% were engineers [2]. This is at a time when engineering research in many fields is becoming progressively interdisciplinary [3]. Bangladesh and Kenya, the current project’s international sites, are also underrepresented sites for international study; only 3% of international study takes place in Africa and 7% in Asia, with most of that going to China [4].

International research experiences in low-income countries can develop values that encourage working with underserved multicultural populations [5] and can result in breakthroughs from looking at a problem from the points of view of more than one discipline or culture [6]. As engineering educators we are increasingly acknowledging the value of involving students in need-based problems [7]. Achievement of educational objectives is enhanced by the student enthusiasm and that often accompanies need based humanitarian projects [7]. Also, human welfare is a clear priority of the engineering profession as evidenced by the NSPE Code of Ethics for Engineers, “*As a Professional Engineer I dedicate my professional knowledge and skill to the advancement and betterment of human welfare . . .*” Nowhere is need greater than in the low-income world. Appropriate technology for meeting humanitarian needs in the low-income world poses its own special problems of adapting design to limited tools, skills and materials; successful adaptation to these parameters enhances engineering learning [8]. We have observed that this project fundamentally changes our students by observing firsthand the level of need, and by experiencing the positive results of their vital and immediate contributions, while simultaneously becoming more receptive to international engineering issues.

The LEGS project provides an exceptional venue for undergraduate international and interdisciplinary collaborative learning on several levels. Among these are working within constraints that are not typically encountered within the U.S. such as having to work within an international context that requires multi-ethnic adaptation and multi-disciplinary interaction, societal constraints that have to be learned and experienced, environmental issues, end-user skill sets, available technology and material, and intercultural communications via verbal interaction and documentation. Thus, success for LEGS is not simply developing a functional design.

Overview of LEGS

The loss of a lower limb, whether by congenital defect or amputation, has a significant adverse impact on basic human mobility. This condition is more severe in low-income countries where active programs of physical rehabilitation, employment retraining and societal reintegration rarely exist and where reliance on physical ability for basic survival is much greater. In many cases, amputees not only suffer the loss of a limb, but also the loss of employment or even social acceptance in the community.

The old proverb, "Give a man a fish and you feed him for a day; teach him to fish and you feed him for a lifetime," expresses the LEGS philosophy. Our primary goal is not to provide individual amputees with a prosthetic leg, but to first *design* a highly functional prosthetic leg that can be manufactured locally in the developing world, and then to facilitate the implementation of this design by working with local medical providers to establish training centers for the technology. Eventually, this approach should enable large populations of amputees over many decades to have access to functional and durable prosthetic limbs.

Thus, our LEGS initiative aims to provide medical providers in low-income nations with appropriate technology for above-knee amputees and equip them with the ability to reproduce and disseminate the technology. Utilizing modern research and advanced technology, LEGS aims to offer solutions to common lower-extremity prostheses challenges found in low-income countries.

History of LEGS

LeTourneau Engineering Global Solutions (LEGS; www.letu.edu/legs) initiative began in 2003 through the vision of Dr. Roger Gonzalez at LeTourneau University with the aim of providing low cost, high-quality prosthetic limbs for individuals in low-income countries.

At the start of this initiative, the LEGS team consisted of five undergraduate engineering students under Dr. Gonzalez's direction. The goal was to create a lower-limb prosthesis for people with amputations above the knee. Our initial design phase involved significant prosthesis research and evaluation of international needs, which resulted in focusing our efforts on the creation of a very low-cost, high-quality polycentric knee. An initial prototype was constructed and underwent mechanical and gait testing as well as evaluation by amputees in the United States.

Our LEGS prototype was initially implemented at AIC CURE, Kijabe, Kenya in December of 2004. Adding a pre-health science student to assist with rehabilitation to the team, we conducted more extensive trials during the summer of 2005. By the fall of

2005, the team expanded to seven engineering students and two pre-health science students, and two faculty members, engineering professor Dr. Stephen Ayers and biology instructor Mrs. Karen Rispin, to lead mechanical design, components testing, rehabilitative needs and human outcomes, respectively. Prosthetic limb expertise was obtained through partnerships with two prosthetists in the United States (Don Cummings, CP, LP, Director of Prosthetics, Texas Scottish Rite Hospital for Children, Dallas, TX and Ricc Gonzales, CP)

During the 2005-2006 academic year, the LEGS team worked on improving the prosthesis, specifically in the areas of aesthetics and alignment. The team developed a preliminary set of recommendations for rehabilitation and follow-up while preparing to test the device in Bangladesh. In collaboration with Memorial Christian Hospital at Mulumghat, the team planned to integrate the LEGS knee design into the Jaipur prosthetic system. After beginning our work in Bangladesh in March of 2006, the team traveled back to Kenya in May, 2006 to investigate LEGS prosthetic devices previously implemented and to update the technology.

Undergraduate students typically spend two years on the LEGS team. During the first year, the junior team members each work under a senior who, in conjunction with faculty, mentors and directs their research. Students only travel when their presence at the international site will further LEGS goals, therefore travel is a privilege that must be earned by proficiency in skills needed overseas.

International collaboration

Because of federal regulations, prosthetic limbs must be prescribed and worn in the United States and undergo medical device evaluation. Licensing the LEGS prosthetic components for use in the United States would be both expensive and time consuming. Since the device is designed for use in very different environmental conditions, we feel that time and resources are better spent testing the LEGS limb in the low-income world, where they are designed to be implemented. Thus, LEGS has active professional collaborations with international partner sites, AIC CURE in Kijabe, Kenya, and Memorial Christian Hospital in Malumghat, Bangladesh. Expansions to Sierra Leone via Mercy Ships, to TATCOT in Tanzania, and to San Salvador are being discussed.

I. Local and Regional politics

Dealing with complex politics successfully in low-income countries takes a deep knowledge of the local culture and political situation. Rather than tackle that task, LEGS has chosen to work through non-profit NGOs that are often older and more stable than the government of the countries in which they work.

Our international NGO partners have long records of good standing with the national government. LEGS has found working with a stable NGO which has been able to maintain good relationships through political upheaval reduces the complications that would ensue from dealing directly with the low-income world governmental organizations.

Regulations and government legislation intrinsic in working with amputees are dealt with through our partner organizations. Cross cultural complications and confusions that waste time and resources are reduced. In addition, safe housing and other health and security issues are dealt with more effectively in conjunction

with organizations that have long histories of working with and housing professional personnel from the United States.

II. Cultural Differences

At our host sites, students on the LEGS team have the privilege of learning from nationals well versed in the local culture and in cross cultural communication. Personnel at these clinics are available and willing to coach students and faculty on cross cultural issues. Yet, even with excellent coaching, such strong cultural differences require that students adapt to a very different working environment while overseas. The local cultures in both Kenya and Bangladesh tend to deal with time differently and they are event oriented rather than clock oriented. These cultures also give a higher priority to building relationships than to accomplishing tasks. For goal oriented engineers and medical personnel with limited time, this combination can be challenging and frustrating.

III. Local technology

The alternatives to the LEGS limb at AIC CURE are prosthetic limbs donated from North America or Europe. The supply of donated limbs is inadequate and not designed for the rough environment. Limited access to maintenance is typical of low-income countries, adding to the inefficiencies of using products from the developed world.

The primary alternate prosthetic device for above-the-knee amputees at Malumghat is the Jaipur limb. Initially designed and built in India, it is widely available and built locally throughout much of the low-income world, especially in Asia. The Jaipur limb consists of a single axis knee (hinge joint) with a locking device, an exoskeletal framework, and a robust but heavy foot with little to no energy return characteristics. Most amputees lock the knee and use the device like a peg leg during gait (walking). Studies indicate that the circumducted limping gait caused by walking with a peg leg is much less energetically efficient and causes more chronic damage than the more symmetrical gait possible with a polycentric knee, like that in the LEGS limb. The LEGS limb with its four-bar polycentric knee allows a more natural motion that can reduce long term chronic injury.

AIC CURE has a prosthetics orthotics shop with typical tools found in prosthetic clinic throughout the low-income world. These tools as a band-saw, drill press, and a sander. When fitting an above-knee prosthetic limb a fiberglass socket is used and an endoskeletal pylon for a shank is attached to a generic sach foot.

The prosthetists in Malumghat Bangladesh are skilled tin-smiths that are able to build and fit an exoskeletal limb quickly using sheet aluminium. The Malumghat prosthetic shop also has similar tools to Kenya. At both sites, LEGS team members have traveled to the nearest large commercial center, Nairobi in Kenya, and Cox Bazaar in Bangladesh, with knowledgeable nationals to search for available materials applicable to the LEGS design.

IV. Cultural Parameters

In the United States, wearing a prosthetic limb that is clearly non-biological in appearance has become acceptable, maybe even favorable, especially among amputees competing in sports. This is not true at our partner sites. The amputees strongly desire a limb that looks as much like their biological limb as possible. This has altered the design goals for LEGS, especially for the development of the foot and of the cosmetic “skin” covering.

In both Kenya and Bangladesh, people often sit or squat on the ground rather than sitting in chairs. Designing a knee, thigh and shin that allow squatting is challenging. In both countries, most people get around by walking, often many miles a day to work, school or to market over rough uneven ground. Access to a prosthetic clinic for maintenance is difficult for most amputees. Therefore a successful prosthetic limb must be robust and nearly maintenance free.

V. Environmental Constraints

Bangladesh and some areas in Kenya experience seasons of intense rain during which an amputee will repeatedly get wet and muddy. Roads and paths are rare. A prosthetic limb will frequently get wet, muddy, or dusty. Understanding the environmental effects on the prosthetic limb impacts design characteristics.

Interdisciplinary Collaboration

I. In the United States

Even in the developed world, engineering research into prosthetic design has an intrinsic interdisciplinary component (Figure I). Unless each of the interactions described in Figure I is successfully in place, the results from validation trials of a prosthetic device are very likely to be skewed by factors not directly related to device function.

In first world countries, the prosthetic supply houses often assist in the process of validating and implementing a new prosthetic design [9]. Device implementation occurs in prosthetics clinics with developed world capabilities which have well established collaborative partnerships with rehabilitation personnel.

II. Overseas

Because the situation at our partner sites differed from that in that in the United States, the plan for validation and implementation of the LEGS limb had to be modified to fit low-income world constraints.

The LEGS goal is to design a prosthetic leg that can be built in the low-income world. Yet, there are no centralized manufacturing companies available who build prosthetics in the low-income world. For a period of time the International Red Cross had been attempting to do so, but because they were displeased with quality control outcomes, the manufacturing of such artificial limbs was moved to Switzerland. In contrast, the Jaipur limb is not regulated or supported from a central location in the same way that Ottobach supports the limbs manufactured by their company.

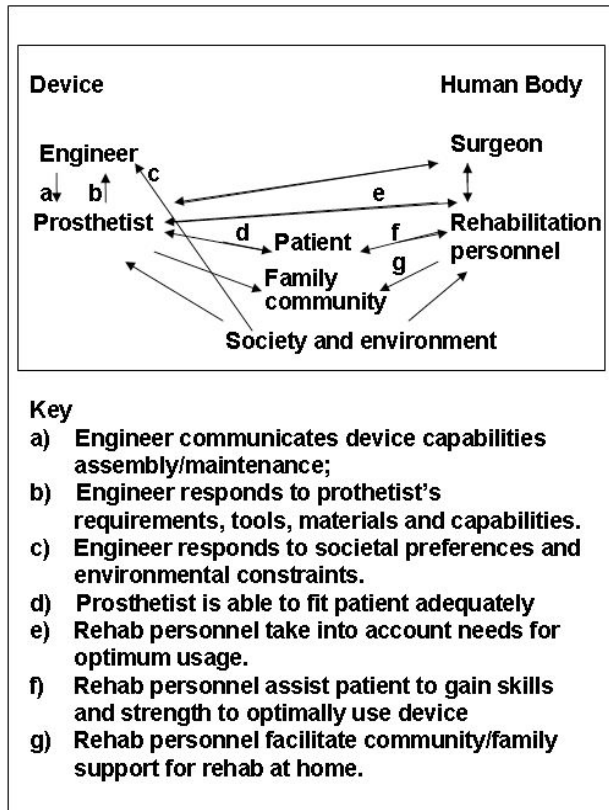


Figure 1 - Collaborations that must occur for successful testing or implementation of a prosthetic device.

Collaboration with Level One Prosthetist

While training of prosthetists is improving in the low-income world, there are very few training institutions that provide training to high levels of expertise [9]. As a result, level one prosthetists are not available at either of our partner sites.

At one of our partner sites, the patient-prosthetist interaction was weak, resulting in repeated difficulty with socket fit in over half of the amputees fitted. Both partner sites requested that a level one prosthetist be included in the collaboration. Steps were taken to establish collaboration with Donald R. Cummings, C.P., L.P., Director of Prosthetics at Texas Scottish Rite Hospital for Children in Dallas as well as with Rick Gonzales C. P., a local prosthetist in Longview.

Collaboration with Rehabilitation Personnel

At all our current partner sites interactions “e”, “f” and “g” on Figure 1 were poorly established, resulting in amputees often receiving no attention from rehabilitation personnel, and only cursory gait training from the prosthetists.

The LEGS limb includes a four bar polycentric knee that articulates in gait and is stable when the leg is extended and bearing weight. If an amputee has been using a prosthetic device such as the Jaipur limb that does not articulate in gait, there is a challenging transition period during which the amputee strives to learn to use the LEGS limb’s capacity for a more biologically normal gait and yet move in a way that keeps the LEGS knee

stable in stance phase. The personnel at the partner sites had not received training in implementing polycentric knees that would allow them to facilitate the patients’ efforts to make this transition.

To help our international partners with this rehabilitation challenge, we established a collaborative effort between 1) the Biology Department at LeTourneau University and 2) professional physical therapists. We realized that research related rehabilitation in the low-income world would benefit pre-medical and pre-physical therapy students more than it would benefit engineering students but also that professionals should be enlisted to enhance the experience. Therefore, consultative relationship has been established with Dr. Robert Gailey PhD PT, an investigator into lower limb amputee rehabilitation at the Miami VA Medical Center and University of Miami, FL, and Kevin Johns, PT, Director of Physical Therapy at the Good Shepherd Sports Medicine Clinic, Longview, Texas.

III. Collaboration within LEGS

The large footprint of the LEGS experience on student learning does not spring from the travel experience alone. The research and travel preparation also stimulate learning. Students and faculty are often compelled to work as a disciplined team under tight deadlines to prepare for international travel. Trips to partner sites typically include one or two faculty members and two to five students. All students are highly motivated to improve the lives of the amputees, working long hours to achieve a difficult mutual student goal. The experience is life changing for all concerned.

Assessment of Learning

I. Questionnaire

International undergraduate learning has often been measured by self reporting [6]. The University of Michigan has a long standing commitment to international experience for undergraduates and has developed and validated a questionnaire to measure international learning [10,11].

Each of the questions was anchored in a five point Likert type scale ranging from 1 (not at all) to 5 (very much). Ingram and Peterson [11] used principal component analysis to identify seven factors which correlate with four primary areas: personal growth, intercultural awareness, intellectual growth and professional development.

To evaluate international learning in undergraduate students on the LEGS team, we selected the questions composed by Ingram and Peterson. We did not utilize the language learning questions since language was not as important to the LEGS project as it was to many of the University of Michigan programs. The questions were administered anonymously as an on-line questionnaire with the assistance of LeTourneau University’s Alumni Office.

Two questions related to academic performance.

1. Participation in international research with LEGS has led to an improvement of my academic performance.
2. Participation in international research with LEGS has enhanced my critical thinking skills.

Seven questions related to personal growth

1. Participation in international research with LEGS has enhanced my independence.
2. Participation in international research with LEGS has enhanced my self reliance.

3. *Participation in international research with LEGS has improved my problem-solving skills.*
4. *Participation in international research with LEGS has helped me develop leadership skills.*
5. *Participation in international research with LEGS has increased my level of comfort with people different from myself.*
6. *Participation in international research with LEGS has increased my ability to interact effectively with people from different backgrounds*
7. *Participation in international research with LEGS has increased my feeling of personal effectiveness.*

Six questions related to Intercultural awareness

1. *Participation in international research with LEGS has enhanced my understanding of international issues.*
2. *Participation in international research with LEGS has contributed to my understanding of other cultures.*
3. *Participation in international research with LEGS has increased my appreciation of human difference.*
4. *Participation in international research with LEGS has increased my curiosity about other cultures.*
5. *Participation in international research with LEGS has contributed to my understanding of my host country..*
6. *Participation in international research with LEGS has increased my understanding of my own culture.*

Four questions related to professional development.

1. *Participation in international research with LEGS has made me reconsider my career plans.*
2. *Participation in international research with LEGS has helped me find professional direction.*
3. *Participation in international research with LEGS has broadened my understanding of the issues that arise when working professionally in a low-income world setting.*
4. *Participation in international research with LEGS has enhanced my ability to work as a team player in solving problems.*

Our sample size is very much smaller than the eleven hundred students whose results were included in Ingram and Patterson's study. Thirteen students have spent two years with the LEGS team and have traveled internationally. We were able to contact twelve of the thirteen; of those, ten responded.

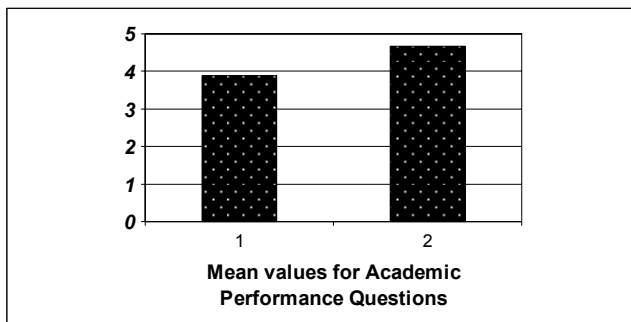


Figure II – Academic Performance Results

All students surveyed felt that the LEGS experience enhanced their critical thinking ability. All but two felt LEGS increased their academic performance. LEGS is a very challenging program that requires disciplined time management.

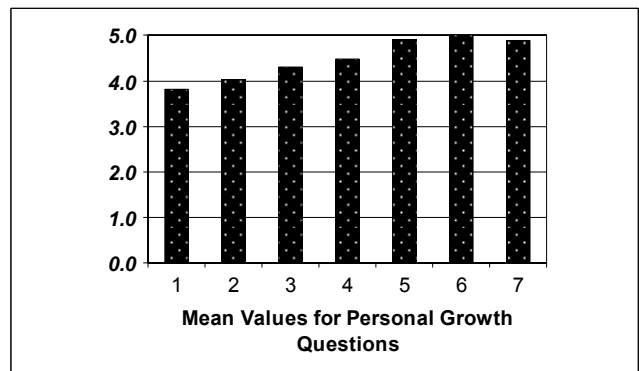


Figure III – Personal Growth Results

All students felt that their problem solving skills, leadership skills, and personal effectiveness had increased as had their comfort with people different than themselves and those from other backgrounds. One student felt that independence and self reliance had not been increased (questions one and 2 in the personal growth category). Students were given the opportunity to write a short essay, and that student commented, "I do not like questions 1 and 2 under Personal Growth. LEGS has NOT increased my independence or self-reliance... RATHER it has increased my reliance and dependence on others... Through LEGS I learned that we HAD to work as a team, and I personally needed the skills of other team members. I would never be able to do this project on my own and I hope my teammates would say that they could not have done the project without me. Never before have I realized how much I needed others."

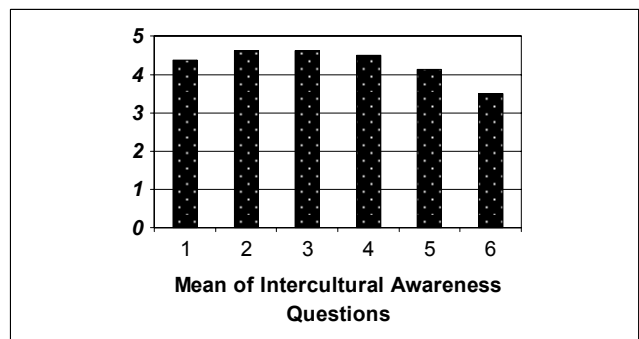


Figure IV – Intercultural Awareness Results.

All students felt their understanding of international issues and other cultures had increased significantly, as had their appreciation for human difference, curiosity about other cultures, and their understanding of their host culture. The mean for question six was lower because many of the students felt that LEGS had not significantly increased their understanding of their own culture.

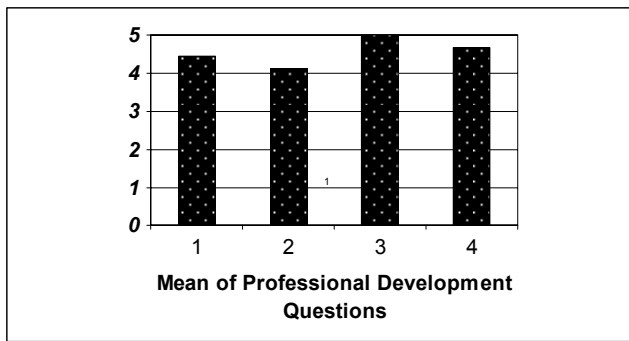


Figure V – Professional Development Results.

Every student surveyed reported that the LEGS experience had “very much” increased their understanding of issues involved with working professionally in the low-income world. All but one said that participation in the LEGS project had caused them to rethink their career plans.

II. Self Reporting

Narratives and essays are recognized methods of assessing international learning (Jackson). The questionnaire we used included one item that elicited a written response. “List professional difficulties you encountered while participating in international research with LEGS and describe how these were overcome.”

One student, as already mentioned, wrote about his or her realization of the importance of working as a member of an interdependent team.

Learning to see others and oneself as individuals irrespective of culture was the theme of another response, “The main difficulty I feel I encountered in international research was bridging the gap between my culture and the culture of the shop workers and patients, and was eventually overcome just by realizing that the countries we live in has much less to do with defining who we are then the things we do and our personalities.”

Another spoke of dealing with a national who behaved in what seemed an unethical manner and realizing that there was a cultural component to the understanding of ethics.

A workable response to technological challenges was central to one answer, “Lack of availability of sophisticated technology/equipment used in the US was overcome by going back to the basics and simplifying our methods/materials.”

The value of working through established NGOs was highlighted by another student’s reply, “Contacts in other countries were hard to come by and finding local supplies was even harder. This was overcome by establishing relationships with organizations already in the country who help to point our team in the right direction and provided local contacts for us.”

Challenges and Personal Costs

I. Time

The LEGS program is extremely time-consuming for the faculty involved. International trips take several weeks and supplant leisure time. The last few weeks before a trip, work at the LEGS laboratory is intense as we make final preparations. In addition, significant coordination is required to secure travel documents, to schedule patients, and to communicate with various entities. A

faculty member must accomplish these tasks to assure all aspects of the international travel so nothing is left to chance.

II. Funds

In addition to grant writing, faculty and students are extensively involved in fund raising. International travel is expensive and difficult to fund sufficiently through private donations. We require students to participate in fundraising and when possible, allow them to apply those funds directly to their travel. Yet, fundraising alone doesn’t guarantee an overseas experience. Not including faculty release time, our annual budget is a minimum of \$30,000 to \$50,000 per year. This level of funding keeps the program functional but not vibrant.

III. Degree Plan Fit

LEGS is a senior design project for the engineering students involved, but it is an extremely challenging project. Students often feel overwhelmed by the amount of work required. We typically see students work an average of 20 to 30 hours per week on this project. Some of our most involved students put in over 40 hours a week, on top of their academic workload. This project can sometimes be all consuming, given that we project overseas travel 6 months in advance and our international partners require extensive planning for our visits. Thus, the decision to cancel a trip is not taken lightly.

IV. Working with Undergraduates

Research with undergraduates presents challenges since engineering students are only with the project for two years. Frequent student turnovers can lead to the loss of understanding and information. This is one of our most difficult challenges. Retraining students on a yearly basis takes time and considerable effort. As the program expands in scope and locations, bringing students to a basic level of knowledge becomes a significant challenge on our human resources resources and time. Currently, we have a LEGS graduate employed as a staff engineer on the project to help with continuity issues.

Benefits

I. Student Success

It is exciting to see the student success resulting from participation in the LEGS program. Several of the engineering students are pursuing graduate school. Others, as a result of our efforts, make it a personal goal to use their skills to help those in need both within and outside the United States. The two biology students who have graduated from the LEGS program are now in medical school. Both found that the LEGS experience came up often in interviews, and both were accepted at multiple medical schools, including out of state institutions.

II. Making an Humanitarian Impact

It’s rewarding to know that our work is beginning to make a difference to under advantaged amputees, and exciting to know that doors are progressively opening to make a more functional prosthetic leg available on a much broader scale. As engineers, we often do not get to see the human impact of our work. This project clearly allows engineers to see how their skills can directly impact human life by giving an amputee greater mobility.

Future Plans

LEGS is still very much a work in progress. We look forward to more challenges as we move forward. The developmental focal

points for this year are (1) foot performance, (2) cosmesis integration, (3) patient and prosthetic evaluation, (3) quantitative field gait evaluation, and (4) facilitating effective rehabilitation and community-based rehabilitation.

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Biographies

Roger V. Gonzalez, Ph.D., P.E. is professor of biomedical & mechanical engineering and the director of the biomedical engineering program at LeTourneau University. He is the founder and director of LEGS and has worked on 6 continents on various international engineering and humanitarian projects. He was an NIH fellow while a research scientist at Northwestern University Medical School and the Rehabilitation Institute of Chicago. He was awarded ASEE's regional outstanding educator award and is as an ABET evaluator. Dr. Gonzalez has been married for 20 years and has two children.

Karen Rispin, M.S., teaches animal physiology and ecology courses at LeTourneau University and is the faculty lead for human outcomes and rehabilitation research on LEGS. Having grown up in Kenya, she has a deep appreciation for the value of international learning experiences. She also performs research on soft tissues of the knee joint as applied to validating computer models. She has eight published books for the popular market.