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Developing Innovative Interdisciplinary Biomedical Engineering Programs in Nigeria: Lessons Learned

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abstract

An interdisciplinary team comprising faculty from the medical school, business school and school of engineering at Northwestern University is in its third year of cultivating “locally grown” healthcare solutions in Nigeria through a grant provided by NIH’s Fogarty International Center. Through a series of training sessions at multiple sites in multiple countries, faculty at the University of Lagos (UINLAG) and the University of Ibadan (UI) are gaining the expertise and developing the infrastructure necessary to identify, design, and commercialize solutions to their own healthcare issues.

The specific aims of the grant are three-fold: 1) Establish new and strengthen existing training programs in biomedical engineering in sub-Saharan Africa; 2) Train biomedical engineers and medical doctors to evaluate newly developed HIV-related and other testing and therapeutic devices; 3) Train post graduates from business schools to scale-up development and launch new healthcare practices. In support of these specific aims we have created four distinct annual training sessions: 1) week-long annual planning meetings hosted by either UNILAG or UI and facilitated by the NU team; 2) ten-week long biomedical engineering training programs at the University of Cape Town (UCT) facilitated by UCT and NU faculty ; 3) participation in two-week long Kellogg Field Studies in Africa; 4) four-week long mentoring visits to NU and the greater Chicago area, including participation in the annual BMES conference. An integral component of the training at NU involves Northwestern faculty members working with faculty from UI and UNILAG to develop BME degree granting programs at their respective universities.

This paper describes these training programs and assesses their ability to meet the specific aims listed above. In addition, we share insights gained through direct and in-direct assessments on how well these programs are addressing the specific aims laid out in grant, identifying what requires modification going forward. We also update the progress made in developing BME degree programs at both universities.

introduction

Medical care and population health in low and middle income countries (LMIC) lag behind wealthier nations because of limited infrastructure and financial and human resources[1,2]. The disease burden is radically different in the developing world with higher mortality rates from human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS), tuberculosis (TB), malaria and other treatable infectious diseases. Infant and maternal mortality surrounding childbirth is unacceptably high. Transplanting Western healthcare systems and technologies to resource-limited settings is a slow and expensive process, and in many instances inappropriate or impossible. Developing new and creative healthcare delivery methods and devices tailored to these environments and conditions will be more effective and less expensive path to improved health. Local research-focused universities can (and should) play a critical role in this scenario[3,4].

Academic institutions have always played an important role in healthcare. Historically the Research University is a site of discovery and innovation as well as a place where future healthcare workers are trained. In the United States and other developed countries great advances have come from a decades-long integration of engineering and medicine, however, in the developing world engineering faculty and physicians collaborate with much less frequency. The objectives of this program address the challenging development issues facing Global Health in relation to the creation of new, innovative, life-saving technologies. Specifically, the objectives are: 1) expand the base of expertise needed and available to address the most pressing problems in global health by developing trans-institutional, problem solving-based research training programs in biomedical engineering that bring together widely diverse experts who work together on research problems in Global Health; 2) Stimulate new knowledge, approaches and solutions in Global Health by putting "innovation" in the Global Health context; and 3) Integrate Global Health research communities within and among institutions by raising awareness and building interdisciplinary biomedical engineering capacity where it is needed the most, in this case, sub-Saharan Africa.

The theme of our program involves the development of effective, affordable, and easy to use innovative biomedical devices that can advance diagnostic and treatment approaches that result in improved survival. We are doing this by establishing comprehensive interdisciplinary training programs in biomedical engineering that include identification of critical healthcare needs, product design, delivery, clinical evaluation, scalability and product launch. Our cross-disciplinary approach involves three key areas of research which only together can lead to improved health and survival: 1) biomedical engineering, 2) medical evaluation, and 3) commercialization. This interdisciplinary training program will provide LMIC faculty and students with a unique comprehensive hands-on learning experience focused on developing innovative global health technologies. The LMIC partners include the University of Cape Town in South Africa, the University of Ibadan, University of Lagos, and the Nigerian Institute for Medical Research in Nigeria.

This paper describes these training programs and assesses their ability to meet the specific aims listed above. In addition, we share insights gained through direct and in-direct assessments on how well these programs are addressing the specific aims laid out in grant, identifying what requires modification going forward. We also update the progress made in developing BME degree programs at both universities.

training at Northwestern University

For each of the past three fall quarters, the biomedical engineering department at Northwestern University has hosted 2-4 engineering faculty from the University of Lagos (UNILAG) and the University of Ibadan (UNI) – See Table I. For 3-4 weeks the faculty remain in the United States where they experience the following:

- Participation in the annual meeting of the Biomedical Engineering Society (BMES). This includes submitting an abstract to the conference and giving a 20 minute presentation on that topic (examples of submitted titles for the 2014 conference are shown in Table II).
- Participation in upper-level BME courses at Northwestern University, including the capstone biomedical engineering design course.
- Visits to Chicago-area biomedical engineering departments (e.g., Marquette University, Illinois Tech).
- Meetings with faculty in the McCormick School of Engineering and Applied Sciences, Weinberg School of Arts and Sciences, Feinberg School of Medicine.
- Tours of engineering labs, medical labs, design facilities, prototyping shops including a rapid prototyping shop comprising over $2M worth of equipment.

Table I. Nigerian faculty participating in Chicago training (2013-2015)

Year	Name	Discipline	University
2013			
	Coker, Akinwale*	Civil Engineering	UI
	Lawal, Taiwo	Pediatric Surgery	UI
	Osuntoki, Akinniyi*	Biomedical Engineering	UNILAG
2014			
	Anyaeche, Osita	Industrial and Production Eng	UI
	Ajibola, Olawale	Systems Engineering	UNILAG
2015			
	Dare, Ademola	Mechanical Engineering	UI
	Adeleye, Rotimi	Systems Engineering	UNILAG

*****Professors Coker and Osuntoki have participated in the Chicago training all three years of the grant.

Table II. Abstracts and manuscripts submitted by Frameworks investigators from Northwestern University, and the Universities of Cape Town, Ibadan, and Lagos to the Biomedical Engineering Society (BMES) 2014 meeting, San Antonio, TX.

Titles	Authors
"Development of Design-Oriented BME Degree Programs in Nigeria"	M. Glucksberg[1], A. Coker[2], A. Osuntoki[3], T. Douglas[4], and R. Murphy[5]
"Numerical Modeling of Magnetic Micropump for Biogenic Bulk Transport in a Biomimetic Microchannel"	E. Ig, A. Dare, and A. Coker[2]
"Design and Construction of a Blood Glucose Meter for Use in Nigeria"	A. Zubair, O. Ibe, and A. Coker[2]
"Design and Construction of a Portable Low Cost Electrical Safety Analyzer for Biomedical	O. Ajibola, F. Ogunwolu, O. Ibidapo-Obe, V. Olunloyo, and A. Osuntoki[3]

Devices"	
"Modelling Gait Syndrome in Huntington prime or minutes disease: the Genetic Algorithm Approach"	A. Osuntoki[3], O. Olawale[2], E. Ajibola[3], C. Esezobor[3], and S. Nwaneri[3]
"Establishment of an Interdisciplinary Biomedical Engineering Programme In Nigeria: Preliminary Observations From The University Of Lagos"	A. Osuntoki[3], O. Olawale[1], E. Ajibola[3], C. Esezobor[3], and S. Nwaneri[3]

[1]Northwestern University, Evanston, IL; [2]University of Ibadan, Ibadan, Nigeria; [3]University of Lagos, Lagos, Nigeria; [4]University of Cape Town, Cape Town, South Africa, [5]Northwestern University, Chicago, IL

Kellogg field studies

Many of the innovative products in Northwestern's medical technology portfolio were identified and refined through market research performed by Kellogg School of Management (KSM) students participating in medical field studies in Africa. Led by Professor Kara Palamountain, co-PI on the Frameworks grant, the Kellogg Field Studies program has engaged more than 300 MBA students over the past ~10 years. These students have comprised over 50 teams and have conducted market entry analysis in over a dozen developing countries, including ten African nations. In addition to product design research, these students have identified the formal and informal processes for launching products in these countries. By participating in these field studies, the Kellogg students learn how to apply theoretical market research methodologies toward the development of specific medical products.

One of the primary goals of the Frameworks grant is to train post graduates from Nigerian business schools to scale-up development of, and launch, new healthcare practices. By participating in the *Kellogg Field Studies* program these graduates will learn how to inform the design and development of innovative medical technologies for developing countries as well as how to train students to collect and analyze information by interviewing and/or observing key individual and organizations. The *Kellogg Field Studies* program is innovative in that it not only considers potential end-users of medical technologies, but also those stakeholders that approve, finance, procure, distribute and maintain these technologies. These stakeholders include:

- Healthcare providers;
- National and regional governments;
- Distribution companies;
- NGOs and international agencies.

Each year two post graduates join Professor Palamountain and her students for two week long field studies in Africa. The objectives of the studies include:

- Identifying the unmet medical needs of the country of focus;

- Defining medical technologies that can address the unmet need;
- Understanding the business, institutional, political and financial framework for implementing new medical technologies in that country;
- Obtain feedback on specific medical technologies underdevelopment at Northwestern University's Center for Innovation in Global Health Technologies (CIGHT).

During the first two years of the Frameworks grant, the *Kellogg Field Studies* program has taken faculty from UI and UNILAG (see Table III) to Tanzania (2014, three participants) and Zambia (2015, two participants).

Table III. Nigerian faculty participating in Kellogg field studies (2014-2016)

Year	Location	Name	Discipline	University
2014	Tanzania			
		Diji, Chuks	Mechanical Engineering	UI
		Orekoya, Samuel	Economics	UI
		Sulaimon, Abdul-Hameed	Business Administration	UNILAG
2015	Zambia			
		Olaniyan, Olanrewaju	Economics	UI
		Kuye, Owolabi	Business Administration	UNILAG
2016	TBD	TBD		

training at the University of Cape Town (UCT)

Biomedical engineering at the University of Cape Town dates back to the 1950s with work done in nuclear medicine by Alan Cormack that led to computer-assisted tomography and the *Nobel Prize in Physiology or Medicine* in 1979. Since that time, the Department of Human Biology has been created which merges biomedical engineering with anatomy, cell biology, physiology and sports science. In 2001 the Healthcare Technologies Management (HTM) Program was added to the department. HTM recognizes that proper management of medical technologies and physical infrastructure is essential for the attainment of affordable and sustainable quality healthcare. In addition, HTM aims for optimal acquisition and utilization of healthcare technologies, including proper planning, evaluation and assessment of health facilities, as part of efficient, cost-effective, multidisciplinary healthcare services. Northwestern University's formal association with UCT began in 2005 with the establishment of the Global Health Technologies (GHT) Program where Northwestern engineering students participate in design and development of appropriate healthcare technologies.

For the past three years faculty from UI and UNILAG (see Table IV) have participated in a ten-week Biomedical Engineering Training Program at the University of Cape Town. The visiting faculty participated in the GHT program, attending and participating in activities related to the following courses:

- BME 388-SA: Healthcare in Resource Poor Environments;
- BME 389-SA: Healthcare Technology Assessment and Planning;
- BME 391-SA: Healthcare Technology Innovation and Design;
- GBL HLTH 314-SA: Health and Community Development in South Africa

In addition, the faculty attended the following UCT courses:

- Biomechanics of the Musculoskeletal System – this course provides background for the design of rehabilitative prosthetic and orthotic devices;
- Introduction to Medical Imaging and Image Processing – this course provides background on the use of imaging as a tool in biomedical engineering, broadly.

Faculty also visited biomedical research facilities at UCT as well as the Heart Museum at Groote Schuur Hospital. They had discussions with UCT faculty involved in medical device innovation, were introduced to the current World Health Organization (WHO) initiative on local production of medical devices as a means of improving access, and attended lectures and project-based discussions offered by NU's GHT program.

Visitors were given the opportunity to attend and participate in the following HTM courses:

- Healthcare Technology Planning and Acquisition;
- Project Management;
- Clinical Engineering Practice;
- Medical Devices and Instrumentation Overview;
- Asset Management of Healthcare Technology and Infrastructure;

These courses expose visiting faculty to the broader context of medical device and healthcare technology innovation, i.e., needs assessment, planning, evaluation, operation and life-cycle management. In addition, faculty are given the opportunity to interact with professional students in the HTM program – all traditional HTM students are employed in the healthcare sector across the African region.

Table IV. Nigerian faculty participating in UCT training (2014-2016)

Year	Name	Discipline	University
2014			
	Zubair, A.R.	Electrical Engineering	UI
	Nwaneri, Solomon	Biomedical Engineering	UNILAG
	Esezobor, Christopher	Pediatrics	UNILAG
2015			
	Akintayo, Folake	Civil Engineering	UI
	Lawal, Oluwatoyin	Oral Pathology	UI
	Adetona, Sunday	Electrical Engineering	UNILAG
	Habeebu, Muhammad	Radiology and Radiotherapy	UNILAG

2016			
	Coker, Morenike	Pharmaceutical Microbiology	UI
	Obed, Rachel	Physics	UI
	Balogun, Adeola	Electrical and Electronics Eng	UNILAG
	Umesi, Donna	Restorative Dentistry	UNILAG

development of biomedical engineering educational programs in Nigeria

Our two educational partners in Nigeria, the University of Ibadan (UI), and the University of Lagos (UNILAG) have been working for the past few years to establish graduate-level biomedical engineering degree granting programs. To put these efforts in context, current materials from UI refer to just two bachelor's level programs at Nigerian universities. One of these programs is at the Federal University of Nigeria at Owerri (FUTO), and was established in 2009; the other program is at the School of Biomedical Engineering Technology, Ahmadu Bello University, in Zaria, and was established in 1993[3]. These programs are designed primarily "to train qualified technical experts to manage and maintain hospital equipment and systems," according to materials from UI, and accordingly the program at FUTO is a Bachelor of Technology in Biomedical Engineering (http://www.nigerianbme.org/nibefutolinkage.html). FUTO also has MS and PhD programs in Biomedical Engineering Technology[3].

While educational programs in BME are rare, Nigeria does have the Nigerian Institute for Biomedical Engineering (NIBE), which was established in 1999, and has held annual BME conferences since that time. In 2009, NIBE created an arm called the College of Biomedical Engineering and Technology (http://www.nigerianbme.org/cbet/), which is responsible for accreditation, development of curricula, setting standards for professional practice, and promotion of biomedical engineering within the country. NIBE is part of the International Federation of Medical and Biological Engineering, so not only is there a professional infrastructure in the country for this field, but links to international organizations as well.

Once in operation, graduate training at UI and UNILAG will work somewhat differently than it does in the US. At UI, students are admitted after a bachelor's level degree in engineering, science or medicine, which is designed to take 10 semesters. Enrolled graduate students are expected to first obtain a Certificate in BME through one or two semesters of full time study (12 units), a Diploma is issued after two to four semesters (24 units total), and finally a Master's degree after four to six semesters (48 units total). Students may leave the program at any of these stages with what is anticipated to be a useful credential for work in the emerging biomedical industry. Typical courses are 2 or 3 units, where 1 unit represents at least 15 hours of contact time, and up to 25 hours if the course includes a laboratory or design component. The Master's degree does not require a thesis, but it does require a 6 unit project course. At each level, there are 6 tracks, each having some required and some elective courses. Five of these tracks are similar to those that would be found at many US institutions: Biomechanics, Imaging,

Systems Modelling, Biomedical Materials, and Biotechnology, and the choices are dictated partially by the perceived needs in the country, and partly by the expertise of available faculty. The other track is Clinical Engineering, which would not typically be found in a US biomedical engineering program, but addresses the needs in Nigeria.

Because the university does not offer a bachelor's of science undergraduate program in biomedical engineering, some of the graduate courses at UI are ones that would be found in most undergraduate BME programs in the US. These include a Survey of Engineering in Medicine and Biology, Biomechanics, Biomaterials, Medical Imaging, Instrumentation, and Biochemistry. Other courses are similar to those that would be expected for upper level undergraduates or graduate students in the US. Some topics, notably imaging and fluid mechanics and transport, are each covered by a sequence of several courses. There is no comprehensive physiology course, which is a mainstay of biomedical engineering programs in the US, but there are specific courses in Cardiovascular Dynamics, Mechanics of the Human Body, and Membrane Biophysics. There is also a lack of courses in cellular and tissue engineering, which even in the US are primarily research fields, so this is appropriate for a postgraduate program preparing students for industry. There are currently no courses specifically listed as design courses, but there is a course in regulatory requirements, which will compensate for the lack of material specific to the medical field in undergraduate engineering programs. The project course may involve design, but its description indicates that enrolled students are to, "undertake a project that will utilize theories to solve problems related to biomedical engineering issues," so it is not necessarily directed toward design.

At UNILAG the Postgraduate Diploma (PGD) program started in 2013-2014. As at Ibadan, the PGD is designed to take two semesters (26 units) and the MS about twice as long (an additional 32 units). The mission statement of the department reflects the dual missions of providing engineers for clinical and technical support for hospitals and manufacturers on the one hand, and research and design of new equipment and software. It is capped by the overarching goal of producing engineers "who will assist the medical team by providing the technological know-how to stabilize the healthcare delivery system and make for self-reliance in health matters in our environment."

The distribution of topics taught in biomedical engineering at UNILAG is similar to that at Ibadan, but at present there are fewer choices, and students at UNILAG will obtain more breadth and somewhat less specialization. All students take a range of courses including numerical methods, biomaterials, biomechanics, instrumentation, and imaging, as well as a course called Basic Biomedical Sciences, which is largely physiology, but also includes cell biology. A somewhat stronger focus on design is evident in course descriptions at UNILAG. The description for the Research Seminar states that "Student teams conceive, design, specify, implement, evaluate, and report on a software and hardware project in the domain of biomedicine." Then the Research Project course, required for the PGD, also emphasizes design: "The student will apply the principles of engineering or bioinformatics design to produce products which meet functional

needs of people with Medical disabilities [and] design and construct either as a team or individually, a working prototype of a new device which solves a problem without current solution." This is challenging because it is to be done in a semester that also includes four other courses. A second project is required for the MS.

Administratively, biomedical engineering at UI is housed in the Department of Mechanical Engineering. At UNILAG the degrees are housed in the Medical School as one of the basic science departments, which was established in 1974. For a time it awarded Diplomas, but then stopped until the recent resurgence of effort[3]. The degree programs are administered through the School of Postgraduate Studies. These programs are almost invisible for the visitor to the websites of the two universities. There is very little information available about the programs, courses, expected career paths, or faculty at either institution. The Mechanical Engineering Department link at UI has nothing about this emerging program. Considering that these are new programs designed to help address serious problems in Nigeria and Africa more broadly, it is interesting that there is so little information available. This is in contrast to US programs, which all have a wealth of information at the department and school websites, and marketing is an emphasis of almost all universities. It is difficult for us to understand how students would obtain enough information about the programs at UI or UNILAG to even apply. The NIBE website is easy to find, but there are no links to these new graduate programs.

results

Participants in each of the training sessions (with the exception of the workshops in Nigeria) are asked to provide feedback on their experiences and how they map onto the specific aims of the Frameworks grant. Below we capture the key insights shared by the program's participants Positive observations are denoted (+); opportunities for improvement are denotes (-).

feedback – training at Northwestern University

- (+) "Gives one first-hand exposure to established BME programs. This helps to see what can be 'borrowed' or adapted for our nascent BME program (in Nigeria)."
- (+) "Critical exposure for evolving interdisciplinary thinking in individuals with the traditional discipline based training."
- (+) "Helps in identifying potential collaborators for research between Nigerian faculties and U.S. faculties."

feedback - Kellogg field studies

- (+) " The involvement of business faculty in the development of business plans for technology/medical products is important and will be very useful in helping to identify priority projects and develop business models for products developed by BME teams."
- (+) "Informed the structure and content of our new MBA program which was being reviewed for accreditation."

- (+) “Provided first-hand experience for the current director of the MBA program (Dr. Sulaimon).”

feedback – training at the University of Cape Town (UCT)

- (+) “Provide unique opportunities for inter-professional learning.”
- (+) “Helping to educate faculty with a diversity of backgrounds to gain a clear view of biomedical engineering within the healthcare system.”
- (+) “Helping to strengthen interdisciplinary collaboration and develop faculty for an interdisciplinary BME program.”
- (+) “The capacity training will further position the University of Ibadan in its quest to train manpower that will provide creative and inexpensive health care solutions for use in Nigeria and Africa in general. This will promote the efforts of the Northwestern University to develop trans-institutional, cross disciplinary and innovative training programs in biomedical engineering in Africa.”
- (-) “The training module should include more hands-on training where participants from diverse backgrounds in engineering and medicine will actually be involved in medical product development.”

feedback – overall

Frameworks training …

- (+) erodes barriers to interdisciplinary training;
- (+) strengthens intra- and inter-institutional collaboration;
- (+) helps to demystify the process of device development;
- (+) promotes innovative thinking and innovation;
- (+) helps us to strengthen each other in our areas of weakness.
- (-) inter-university collaboration has been slow to develop and hinders progress on the development of medical devices. The use of information and communication technology is still limited in Nigeria.

discussion and future work

Seven Nigerian faculty have visited Northwestern University to participate in the training program, and another 11 have participated in the program based in Cape Town. Five faculty have participated in fieldwork in Tanzania and Zambia with Northwestern’s Kellogg School of Management. Training is proceeding through a combination of traditional classroom-based learning and structured in-country field research in partnership with students and faculty from Northwestern University and the University of Cape Town. Through these activities faculty and clinicians are participating in the identification and development of healthcare technologies

appropriate for their local and regional settings. Healthcare technologies can include anything that significantly affects outcomes and cost-effectiveness of healthcare delivery including medical devices, therapeutic interventions, information systems and mobile communication technologies. Selected trainees with biomedical and behavioral science backgrounds in adult and pediatric medicine are directed towards evaluating the newly developed technologies. Faculty trainees in business are instructed and mentored in defining the most appropriate medical technologies needed in their home country along with the tools needed to approve, finance, procure, distribute, use and maintain these medical technologies. These trainings provide opportunities for inter-professional learning, enhance interdisciplinary thinking and project focused cross-disciplinary team building skills in faculties who were trained in the traditional discipline based mode. The ultimate result of these efforts will be to support the expansion in size and scope of the recently established departments in biomedical engineering at the Nigerian institutions.

The faculty training programs supported by the Frameworks grant continue to build upon the experiences of the Center for Global Health in the Feinberg School of Medicine, the Center for Innovation in Global Health Technologies in the McCormick School of Engineering and the Global Health Initiative at the Kellogg School of Management at Northwestern University, as well as the long record of academic excellence at the University of Ibadan, the University of Lagos, and the University of Cape Town. The close collaboration of basic, applied, and clinical research involving medical, engineering, and business schools may serve as one model for cross-disciplinary innovation in health and healthcare technologies; more likely, however, our efforts will result in a model more suited to particular situations in Nigeria, a country rich in resources and with significant technical capacity within their universities that has not yet developed medical products focused on addressing local and regional needs. Like most medical systems in LMIC, available technologies are imported from the US, Europe, and Japan. Much of the population of these countries and others in sub-Saharan Africa suffers from medical, economic and social conditions that differ in both degree and kind from the environment where these technologies were developed. Local BME programs focused on appropriate technologies that understand the challenges of these environments are urgently needed to facilitate development and commercialization of the devices and processes needed to improve healthcare in Africa.

Moving forward there is a definite need to better communicate the learning objectives for each of the four training experiences to the grant's trainees. While effort has been made to map these experiences onto the specific aims proposed in the Frameworks grant, detailed learning outcomes have not been uniformly identified (e.g., training at NU), and, as a result, have not been integrated into an assessment tool for measuring the learning occurring through these experiences. One potential solution to this problem is to use the reflections that we have collected to date to identify what the participants have learned through each of their experiences

and what they would have liked to have learned but have not. These skills and concepts can be integrated into a self-efficacy pre- and post-test survey instrument (see the work of McKenna and Hirsch[10] for an example of a similar effort to measure learning of the design process by undergraduate engineering students). In addition to the summative reflections that we have collected (i.e., reflections collected after the training has been completed), we should complement these with more frequent journaling of the experiences using prompts provided by the trainers/faculty leading the experience. These reflections would provide feedback about specific aspects of the training as opposed to the training as a whole. The feedback could then be used to inform, and potentially, upgrade the training experiences being offered.

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