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Medical device compendium for the developing world: a new approach in project and service-based learning for engineering graduate students

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ABSTRACT: Project and service-based learning approaches have proven effective in preparing new generations of engineers to tackle emerging local and global challenges. However, such approaches are mostly limited by the boundaries of the classroom and the academic term. This article describes a case study of a unique and inexpensive project- and service-based learning approaches that were carried out first within the confines of a classroom and later transitioned to the real world as a practical product through a co-curricular activity. An evaluation of the educational outcomes of the course of study found an overall positive impact on student learning. The course itself resulted in the establishment of a Global Health Medical Devices Compendium, a new open-source information-sharing platform that presents available medical devices designed for, or implemented in, the developing world.

Keywords: Project-based learning, service-based learning, active learning, experiential learning, peer-to-peer learning, health technology, medical devices, global health, curricular and co-curricular partnership, engineering education

INTRODUCTION

The rapidity of the changes in the world's interconnected social, cultural, political, financial and technological sectors has tremendous impacts on these sectors' forward formation and advances. Today's engineers, globally recognised for their innovative approaches, strong problem-solving and communications skills and leadership, are being educated and trained to assume vital roles. A diverse global community invariably requires a new set of skills to address future concerns in the energy, natural resources, environmental sustainability, security, finance and health care sectors. A recently coined term, *engineer of 2020*, alludes to the dynamism, agility, resilience and flexibility required to take on both the known and unexpected challenges ahead [1]. As Dym et al emphasise, academia should prepare the engineer of 2020 by offering open-ended, non-linear, interdisciplinary, project-based courses [2]. In other words, creative outcomes that benefit local and global communities by taking on diverse challenges will be expected from the future graduates of engineering schools.

In its 1995 report, *Systematic Engineering Education Reform*, the United States' National Science Foundation (NSF) called for reforms in engineering education that emphasise project-based learning (PBL), among other suggestions [3]. Prince defines PBL as *an instructional method where relevant problems are introduced at the beginning of the instruction cycle and used to provide the context and motivation for the learning that follows* [4]. Barrows suggests six characteristics of PBL: learning is student-centred; learning occurs in small student groups; instructors are facilitators or guides; problems are the organising focus and stimulus for learning; problems are the vehicle for the development of clinical (real-world) problem-solving skills; and new information is acquired through self-directed learning [5]. Project- and service-based learning, regarded as approaches that bridge the gap between theoretical knowledge learned through fundamental and engineering courses and practice in engineering fields, have been shown to be suitable and effective pedagogical approaches [6].

From Aalborg University in Denmark, which claims to be the first institution of higher education founded on the premise of PBL, to recent adoptions of PBL and active learning by the University of Delaware, the University of Botswana, McMaster University, Technion Institute of Technology, etc, more engineering departments are pursuing active engagement to prepare their students for the global challenges and opportunities of the future [7-12]. Project- and service-based learning motivate students, leaving them with a lasting sense of their impact. One drawback is that PBL and service-based learning can be prohibitively expensive for students, due to the costs of travel, insurance, etc. Virtual service learning can provide a less costly but still effective service learning experience. Even better, combining the learning process with a community need and a virtual platform can allow students to engage in meaningful learning and outcomes that benefit the host and/or global communities [13].

The cost of healthcare and the inequities in access to proper care are global concerns. For example, in 2009, Luxemburg and Norway spent US$5,538 and US$4,502, respectively, on healthcare expenses per capita, whereas India and Myanmar spent only US$38 and US$4 per capita, respectively [14]. Notably, the World Health Organization (WHO) reports that up to 80% of health technologies in resource-limited settings are acquired by donation, yet one study finds that only up to 30% of donated technologies are operational [15][16]. Major reasons for the ineffectiveness of health technologies in the developing world include: inappropriate donations and designs, lack of training and poor maintenance [15]. Hence, there is a strong need for healthcare providers, decision-makers and health technology designers to learn about the availability of appropriate, low-cost and effective technologies.

This article describes a unique approach pursued through a course offered to an interdisciplinary group of engineering graduate students and its follow-up co-curricular activities. The approach utilises project-, service- and experiential-based learning methods. The outcome is the creation of an on-line open-access compendium of medical devices designed for or implemented in the developing world. This approach highlights the potential strengths and impacts of classroom work combined with a service-based learning process and a common goal of creating a tangible outcome.

OVERVIEW OF COURSE AND CO-CURRICULAR ACTIVITY

The course *Design for Global Health: Sustainable Technologies for the Developing World* (three credit hours) was offered by the College of Engineering at the University of Michigan (UM) during the winter 2010 semester. The course developer's objective was to focus on technologies that are designed to prevent, diagnose or treat the top ten leading causes of death in low-income and middle-income countries, as well as maternal and infant health (United Nations' Millennium Development Goals 4 and 5) [17]. It was open to graduate students from any engineering field. The students were evaluated based on discussion participation (40%), interactive assignments (40%) and a final project (20%). Fifteen students (one doctoral, 12 Masters and two Bachelor's degrees) from mechanical engineering (nine students), biomedical engineering (five students) and the school of information (one student) enrolled. Table 1 shows the weekly class schedule.

Table 1: Weekly class schedule.

Weekly Health Topic Overview Presentation	Weekly Technology Review Presentation	Weekly Discussion Topic
Lower respiratory infections, chronic respiratory diseases	Finalise the technology review template	Medical anthropology
Cardiovascular diseases	Lower and chronic respiratory infections	Impact of culture on engineering design
HIV/AIDS	Cardiovascular	Needs assessment and ethnographic research
Diarrheal diseases	HIV/AIDS	Point-of-care diagnostics
Malaria	Diarrheal diseases	Clinical trial ethics and design
Tuberculosis	Malaria	Entering and engaging with a community
Child and infant mortality	Tuberculosis	Infectious diseases
Maternal mortality	Infant and child mortality	Making health technologies commercially sustainable in the developing world
Cancer	Maternal mortality	Human resources for health
Road traffic accidents	Cancer	Chronic diseases
Type II diabetes	Road traffic	Design for road safety
Physical disabilities	Type II diabetes	Biomedical ethics
Course outcome evaluations and next steps (focus group discussion)	Physical disabilities	N/A

Pairs of students volunteered to become health topic leaders for each of the health topics listed in Table 1 during the first week of the semester. Each class began with a student leader-based presentation of a specific health topic, including general aetiology, global endemic status and examples of relevant health technologies. The student health topic leaders, then assigned the remaining students in the course with the tasks of identifying and evaluating the range of technologies designed for or implemented in the developing world for the prevention, diagnosis and treatment of the particular health topic. Student leaders created, communicated and managed a technology/solution search framework during the ensuing week, and compiled and analysed the student-generated case studies. Finally, they prepared a presentation of the findings for the next class. During the second hour of each class, a student topic leader led the evaluation discussion of technologies identified for a health topic introduced in the previous week to capture their strengths and shortcomings. The third hour was devoted to a student-led open discussion, relevant to global health and technology, based on previously distributed reading assignments. Each week, an expert in the topic joined the open discussion. The course also offered an opportunity to spend the University's midterm break conducting clinical observations in Nicaragua to learn about the challenges with health technologies in developing settings. Accompanying CARE International (a global NGO fighting poverty), the students visited 10 urban and rural health facilities.

During the first week of the course, the students were assigned to develop candidate case study templates that captured the characteristics and specific information of identified technologies. The final version of the case study template, shown in Table 2, was developed based on categories informed by the health technology reports of the WHO, the World Bank, etc.

A health care technology was defined as *devices, drugs, medical, and surgical procedures…used in the prevention, diagnosis and treatment of disease as well as in rehabilitation, and the organizational and supportive systems within which care is provided* [18]. On-line searches were the primary method used to identify technologies. Information sources included scientific literature and patent databases, such as PubMed, Google Scholar, Scopus and USPTO. Search keywords were chosen based on the technical, clinical and socio-cultural aspects of each health topic. Patent searches, when appropriate, were performed to evaluate the originality of a technology as needed. The identified technologies were reviewed by student topic leaders and stored in an internal database using the case study template.

Table 2: Case study template used to capture details of the identified technologies.

Title	Classification	Stage	Who made it?	Where is it used?	Cost	Innovation	Reference
Tech name	Diagnostic, Preventative or Treatment	Concept, Clinical, Market	Inventor, etc	Location(s) of implementation	USD	Approach in design, business model, etc	Full reference list

Throughout the course, the students were expected to provide continuous peer-to-peer feedback regarding best practices and methodologies used to identify the appropriate technologies. Using virtual platforms, the students discussed the strengths and weaknesses of the design, engineering and implementation approaches of the technology cases identified. For the final project, each student wrote a mock Gates Foundation Grand Challenges Exploration grant proposal for a health technology, which included both technology and business development plans, inspired by the weekly technology reviews, in-class discussions and experiential learning opportunity.

After the course, a subset of students formed a working group as a co-curricular activity that was supported by the University of Michigan Center for Global Health and open to the campus community. The goal was to continue refining the technology case studies identified during the winter 2010 course and to prepare a compendium of health technologies for public access. Over 30 undergraduate, masters and doctoral students from engineering, medicine, public health, public policy, etc, joined the team during the academic years 2010-2011 and 2011-2012. They created three sub-teams to fulfil the following tasks:

1. *Fact checkers* evaluated and refined the existing content generated in the *Design for Global Health* course.
2. *Content generators* identified new technologies that were not covered in the course.
3. *Editors* reviewed and prepared for the open-access compendium.

EDUCATIONAL OUTCOME

Surveys were performed to evaluate the educational impact of the course on students' perceived abilities in specific engineering design-related areas of interest and to measure self-reported professional progress in an interdisciplinary environment with a non-traditional teaching agenda. Focus group discussions (FGDs) at the end of the course obtained feedback from students about teaching methodology, general direction of the course and the impacts on students' academic and professional growth.

The students were asked to express their level of agreement with each statement using a Likert scale of 1-5 (1: Strongly disagree, to 5: Strongly agree). Table 3 shows the statements and responses documented before and after the completion of the course. The results were analysed using a paired sample *t*-test. Compared with the beginning of the course, there was a statistically significant increase in level of confidence after completion of the course for statements 1, 3, 4, 5, 6, 7, 8, 10, 12. Perceptions regarding student understanding of how values, methods and ethical frameworks evolve in another culture were also higher after completion of the course. However, the results show no statistically significant improvement in statements 2, 9, 11 and 14.

During the FGDs, students emphasised the course's unique approach, which assigned them to identify technologies and solutions for the most pressing global health challenges. Students cited the pedagogical style employed in the course as the primary factor for promoting self-confidence with the subject matter presented. This approach was explicitly noted to differ from students' traditional engineering courses in which content is presented by the instructor in a top-down manner. The students stressed the importance of the off-campus experiential learning opportunity in Nicaragua, which helped them to contextualise the need for identifying appropriate health technologies for the developing world and to share their findings with stakeholders. There was unanimous agreement that the *purpose driven* approach motivated students to actively engage throughout the course.

Table 3: Students' responses regarding their design task confidence, before and after course completion.

Statement: I am able to …	Pre: Mean (SD)	Post: Mean (SD)	*P value*
(1) identify the needs of the targeted community/end-user/customer/ stakeholder.	3.7 (0.83)	4.3 (0.61)	0.026
(2) communicate those needs within an intercultural group setting.	3.7 (0.91)	4.0 (0.39)	0.22
(3) identify cultural and social influences on design.	3.1 (1.3)	4.6 (0.51)	0.0030
(4) conduct clinical observations for the purpose of needs assessment and problem definition.	3.3 (1.1)	4.5 (0.85)	0.0070
(5) generate case studies of engineering successes and/or failures.	3.1 (1.2)	4.9 (0.27)	<0.001
(6) lead a team of interdisciplinary diverse individuals.	3.9 (0.53)	4.4 (0.65)	0.026
(7) recognise ethical issues involved in designing global health technologies.	3.4 (1.1)	4.2 (0.89)	0.022
(8) recognise ethical issues in testing global health technologies.	2.7 (1.1)	4.3(0.47)	<0.001
(9) consider alternative points of view/others' perspectives.	4.4 (0.50)	4.6 (0.51)	0.34
(10) conduct an in-depth needs assessment.	3.5 (0.76)	4.1 (0.66)	0.0020
(11) conduct collaborative problem definition.	3.9 (0.86)	4.4 (0.63)	0.068
(12) collaborate with stakeholders who define problems differently from one another, including non-engineers.	3.7 (0.61)	4.4 (0.51)	<0.001
(13) assess the implications of alternative solutions for stakeholders.	3.4 (0.76)	3.9 (0.47)	0.089
(14) exercise leadership by making trade-offs among alternative stakeholders, alternative problem definitions and alternative perspectives about what is taking place.	3.4 (0.94)	3.9 (0.92)	0.17
(15) I have an understanding of how values, methods, ethical frameworks and beliefs have evolved in a culture other than my own.	3.4 (1.2)	4.6 (0.50)	<0.001

The course resulted in a new appreciation of simple design, low-cost devices. The FGDs identified the following four trending themes among technology solutions:

1. Simple design: *Engineers must know that the most complicated technologies are not always best. One example we identified was a low-cost infant warmer, similar in form and function to a sleeping bag, designed to keep babies warm at a fraction of the cost of a traditional incubator.* (Student's feedback)
   Some of the effective designs were also very simple, like a device fashioned from a cardboard box which would train doctors to perform laparoscopic surgery. (Student's feedback)
2. Nature-inspired design: *Those that harness nature reap the benefits. Take the life-sustaining Moringa tree (Moringa oleifera), a vegetable tree that provides many essential vitamins and minerals, or* golden rice, *fortified with vitamin A, both crops could be used to combat malnutrition in developing countries.* (Student's feedback)
3. Cell phone–based design: *As cellular phones grow in both prevalence and power, so does their potential as health platforms. Several initiatives currently in development would utilize cell phones, with different approaches, to enhance delivering appropriate care.* (Student's feedback)
4. User-centred design: *The idea of the necklace with colored beads to allow a woman to keep track of her menstrual cycle and which days are safer for sex was brilliant, that was a simple and very much easy-to-use design*. (Student's feedback)

PROFESSIONAL OUTCOME

By the end of the course (April 2010), over 600 case studies of health care technologies were generated, reviewed and systematically stored in an internal database as solutions to prevent, diagnose or treat the top ten leading global causes of death, and infant and maternal mortality in developing countries. Throughout the course, students and the course's instructor had consulted about potential methods to present and share the outcomes in the form of a compendium of global health technologies. The subset of students and student volunteers, directed by the course's instructor and a former course participant (co-author), joined forces, as a working group, for almost two years after the course to refine the data collected and to identify additional case studies. To enhance the quality of the compendium and prepare it for global access, the definition of a medical device as suggested by the Global Health Harmonization Taskforce [19] was adopted to establish a uniform framework for evaluating each technology. A uniform definition is particularly important for reducing uncertainties, since *technology* can be interpreted in different ways.

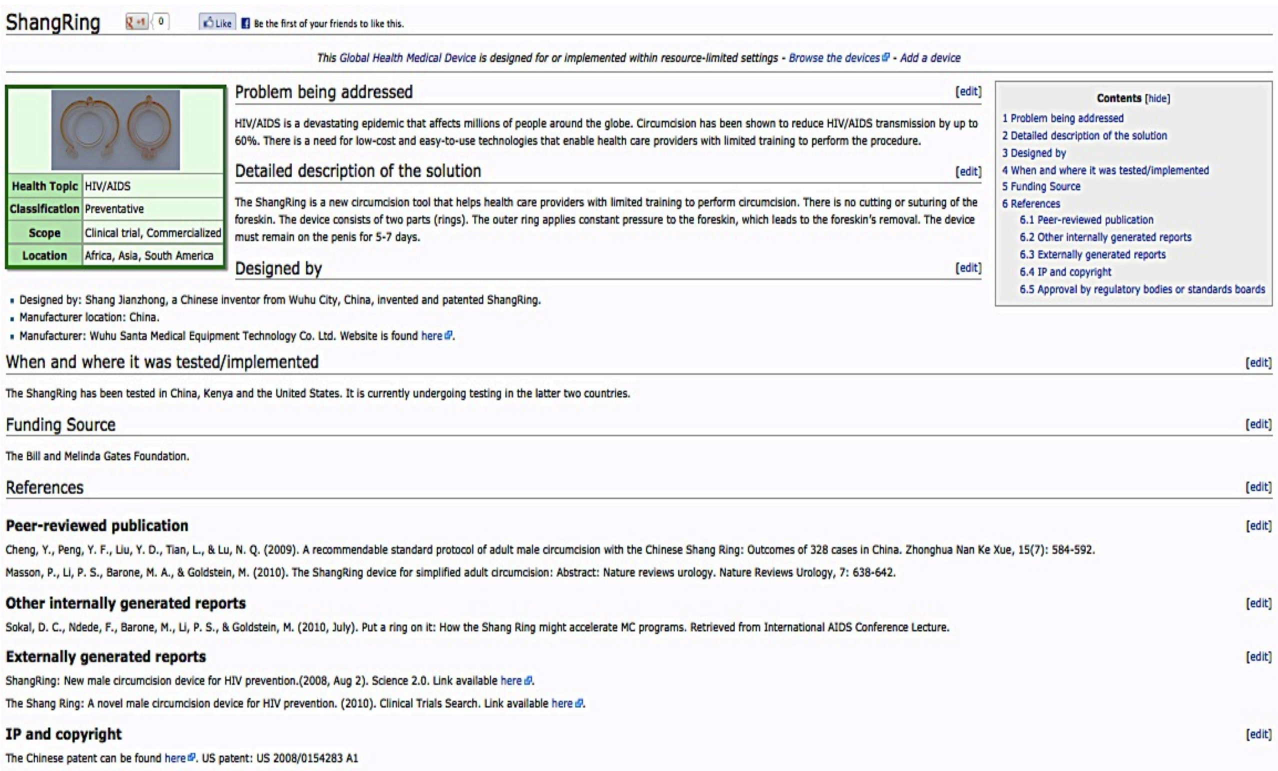
In April 2012, the working group launched an open-source, Wiki-based compendium of global health medical devices [http://www.appropedia.org/Portal:Medical_Devices]. Their *UM Global Health Medical Devices Compendium* is hosted by the Appropedia Foundation, a non-profit entity that *shares knowledge to build rich, sustainable lives*. The Appropedia platform is licenced as Creative Commons-Share Alike. The partnership between the UM and the Appropedia Foundation provides an effective virtual service learning engagement.

A few months after launch, the UM Medical Devices Compendium is proving to be a data-rich component of Appropedia.org. Contributors use a specialised entry form that helps keep devices consistent across the site and across contributors. The form has selectable items for four different properties of information: *Health Topic, Classification, Scope* and *Location*. Users can access the open information via a portal-style landing page, specific disease pages, searches and a drill-down browser as shown in Table 4.

Table 4: Global Health Medical Devices Compendium technology case study content.

Health Topic	Tuberculosis, Malaria, HIV/AIDS, Cardiovascular Diseases, Cancer, Infant and Child Mortality, Maternal Mortality, Mental Health, Nutrition, Physical Disabilities, Respiratory, Road Traffic Accidents, Type II Diabetes, Waterborne Diseases
Devices' Classification	Preventative, Diagnostic, Treatment
Devices' Scope	Prototype, Clinical Trial, Market
Location	Africa, Asia, Australia, Europe, North America, South America

The home page, in portal-style, describes the Compendium and displays three devices and images per health topic. The health topic pages display a table and image of all of the relevant devices. The table is sortable by name, classification, scope and location. The drill-down browser allows a user to browse through devices by selecting properties from topic, scope, classification and/or location. For example, a user wanting to learn about commercialised, preventative devices for HIV/AIDS currently available in Africa can use the browser to find the list of devices. At any point during the drill-down browsing, the user can select from the resulting list and view a full description of the device (e.g. ShangRing, Figure 1). Every device page section is editable, allowing users to update information. Thus, the Compendium functions as a critical and timely resource.



ShangRing
Be the first of your friends to like this.

This Global Health Medical Device is designed for or implemented within resource-limited settings - Browse the devices - Add a device

Health Topic	HIV/AIDS
Classification	Preventative
Scope	Clinical trial, Commercialized
Location	Africa, Asia, South America

Contents [hide]
1 Problem being addressed
2 Detailed description of the solution
3 Designed by
4 When and where it was tested/implemented
5 Funding Source
6 References
6.1 Peer-reviewed publication
6.2 Other internally generated reports
6.3 Externally generated reports
6.4 IP and copyright
6.5 Approval by regulatory bodies or standards boards

Problem being addressed [edit]

HIV/AIDS is a devastating epidemic that affects millions of people around the globe. Circumcision has been shown to reduce HIV/AIDS transmission by up to 60%. There is a need for low-cost and easy-to-use technologies that enable health care providers with limited training to perform the procedure.

Detailed description of the solution [edit]

The ShangRing is a new circumcision tool that helps health care providers with limited training to perform circumcision. There is no cutting or suturing of the foreskin. The device consists of two parts (rings). The outer ring applies constant pressure to the foreskin, which leads to the foreskin's removal. The device must remain on the penis for 5-7 days.

Designed by [edit]

- Designed by: Shang Jianzhong, a Chinese inventor from Wuhu City, China, invented and patented ShangRing.
- Manufacturer location: China.
- Manufacturer: Wuhu Santa Medical Equipment Technology Co. Ltd. Website is found here.

When and where it was tested/implemented [edit]

The ShangRing has been tested in China, Kenya and the United States. It is currently undergoing testing in the latter two countries.

Funding Source [edit]

The Bill and Melinda Gates Foundation.

References [edit]

Peer-reviewed publication [edit]

Cheng, Y., Peng, Y. F., Liu, Y. D., Tian, L., & Lu, N. Q. (2009). A recommendable standard protocol of adult male circumcision with the Chinese Shang Ring: Outcomes of 328 cases in China. Zhonghua Nan Ke Xue, 15(7): 584-592.

Masson, P., Li, P. S., Barone, M. A., & Goldstein, M. (2010). The ShangRing device for simplified adult circumcision: Abstract: Nature reviews urology. Nature Reviews Urology, 7: 638-642.

Other internally generated reports [edit]

Sokal, D. C., Ndede, F., Barone, M., Li, P. S., & Goldstein, M. (2010, July). Put a ring on it: How the Shang Ring might accelerate MC programs. Retrieved from International AIDS Conference Lecture.

Externally generated reports [edit]

ShangRing: New male circumcision device for HIV prevention.(2008, Aug 2). Science 2.0. Link available here.

The Shang Ring: A novel male circumcision device for HIV prevention. (2010). Clinical Trials Search. Link available here.

IP and copyright [edit]

The Chinese patent can be found here. US patent: US 2008/0154283 A1

Figure 1: Example of a complete device description (ShangRing: a male circumcision device to assist with prevention of HIV transmission).

DISCUSSION

Project- and service-based learning add new dimensions to engineering education by providing context and a stronger sense of purpose, while introducing new learning content. Findings from earlier literature agree on the positive student learning attitudes created by PBL [4]. Six characteristics of PBL, as Barrows suggests, were pursued in the teaching model presented: the learning process was student-centred and occurred within a small student group; the instructor played the role of facilitator; the challenge to address the need for a centralised information system for global health technologies was the organising focus and stimulus for learning; and new knowledge was acquired through self-directed learning. The class time was broken into three sections: group reporting findings about global health technologies; mini-lectures providing information about the state of a given health topic; and general class discussion and future plan of work, as illustrated in previous literature, as an effective use of class time in PBL [20]. Even though many of the students who participated had already been exposed to design courses (e.g., senior capstone design), the teaching outcome revealed improvement in all of the areas the students were asked about before and after attending the course.

The educational and professional outcomes of this novel course reveal enormous potential for service-based learning approaches that extend beyond the typical boundaries of classrooms and academic terms. The Compendium originated within a class environment, but has already demonstrated its effectiveness for individual end-users, federal institutions, such as the Center for Disease Control in the US, and international organisations, such as the WHO’s Medical Devices Unit.

The Virtual Service Learning (VSL) model pursued here allows a cost-effective and accessible way for students to engage in project- and service-based learning courses offered by their host institution. VSL provides an avenue to meet education for sustainable development, while bolstering current sustainable development, thereby building future leaders and current solutions [21]. By leveraging an on-line open platform, such as Appropedia, students can have wide and lasting impacts. The partnership between the UM and Appropedia signifies the potential in cross-collaboration between institutions with different core competencies.

In this collaboration, the interdisciplinary group at the UM initiated an educational platform through which extensive, needed content that focussed on global health technologies was generated, whereas Appropedia provided an on-line platform that encourages contributions from any interested party, while monitoring the content. Since its inception in April 2006, Appropedia has been edited over 20,000 times, creating over 35,000 pages from almost 10,000 registered users. Appropedia has been used by teachers and courses to improve service learning and sustainability education, and has been documented in dozens of peer-reviewed journal articles, reports and books (e.g. UNESCO’s *Issues, Challenges and Opportunities for Development*, etc. [22]) on service learning, sustainable development, humanitarian engineering and open-source appropriate technology.

Drawing upon Appropedia’s global community of practitioners, academics and enthusiasts allowed the UM *Design for Global Health* course to disseminate its Global Health Medical Device Compendium quickly. Partnering with an existing on-line platform meant that the UM team could focus on content creation rather than technical aspects. In the six months since the Compendium’s launch, its pages were accessed over 60,000 times. This type of partnership is critical for academic institutions intending to address myriad global needs cost effectively and provide transformative learning opportunities for students on- and off-campus.

CONCLUSION

Sheppard writes that *Engineers scope, generate, evaluate, and realize ideas* [23]. The National Academy of Engineers states that *We aspire to a future where engineers are prepared to adapt to changes in global forces and trends and to ethically assist the world in creating a balance in the standard of living for developing and developed countries alike* [1]. The project- and service-based learning approaches used during the course and the co-curricular working groups formed by students and volunteers described in this article exemplify how interdisciplinary groups of engineering students can contribute to the global community, while achieving learning outcomes. VSL provides an opportunity for engineers at any stage of their careers to experience the effectiveness of their projects and receive real-time feedback by combining the learning process with a community need and a virtual platform.

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BIOGRAPHIES

Kathleen Sienko is an Assistant Professor in the Departments of Mechanical and Biomedical Engineering at the University of Michigan. She created and taught the course, *Design for Global Health: Sustainable Technologies for the Developing World* in 2010 and directed the subsequent student working groups. She holds a PhD from the Harvard-MIT Division of Health Science and Technology's Medical Engineering Program, an SM in Aeronautics & Astronautics from MIT and a BS in Materials Engineering from the University of Kentucky. She directs both the Sensory Augmentation and Rehabilitation Laboratory (SARL) and the Laboratory for Innovation in Global Health Technology (LIGHT) at the UM. She has led efforts at the University of Michigan to incorporate the constraints of global health technologies into undergraduate and graduate engineering design. Professor Sienko's educational initiatives have been recognised by the National Academy of Engineering as part of its Frontiers of Engineering Education Symposium and she has been awarded the UM Undergraduate Teaching Award, the Provost's Teaching Innovation Prize, the UM College of Engineering Raymond J. and Monica E. Schultz Outreach and Diversity Award, the UM Mechanical Engineering Achievement Award and the UM Pi Tau Sigma Professor of the Term Award.

Amir Sabet Sarvestani is a doctoral student in the Design Science Program at the University of Michigan. His research interests include medical device design and development with a focus on resource-limited settings. He is also interested in the decision-making processes of different stakeholders when choosing and adopting health technologies. He holds a BS and an MS in biomedical engineering from the University of Michigan. He has worked in the WHO's Medical Devices Unit in Geneva, Switzerland. Amir completed the *Design for Global Health* course and led the subsequent working groups to finalise and launch the UM Global Health Medical Devices Compendium.

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