AC 2012-3829: OVERVIEW OF THE FIRST YEAR OF AN INNOVATIVE SCIENCE EDUCATION AND ENTREPRENEURSHIP VENTURE

Ms. Kelsey B. Hatzell, Pennsylvania State University

Kelsey B. Hatzell is a National Science Foundation Graduate Fellow studying material science for her doctoral studies. She received a bachelor's of science degree in general engineering, and a bachelor's of arts in economics from Swarthmore College. She also holds a master's of science in mechanical engineering from the Pennsylvania State University.

Marta C. Hatzell, Pennsylvania State University

Marta C. Hatzell is a National Science Foundation Graduate Fellow studying mechanical engineering for her doctoral studies. She received a bachelor's of science degree and a master's of science degree in mechanical engineering at Penn State. She is currently working on a master's of engineering in environmental engineering concurrent to her mechanical doctoral studies at the Pennsylvania State University.

Mr. Min Young Pack, Pennsylvania State University

Min Young Pack is a graduating senior at the Pennsylvania State University, studying engineering science. He is member of the Schreyer's Honors College, where his senior thesis explored the universal joint concept.

Ms. Johanna Gretchen Hatzell, Pennsylvania State University, University Park

Johanna Gretchen Hatzell is a sophomore in the Schreyer's Honors College at Penn State University, studying industrial engineering and entrepreneurship.

Mr. Samir Narendra Patel, Pennsylvania State University

Samir Narendra Patel is a Schreyer's Honors College student double majoring in biology and economics. He has taken part in several ventures with the Humanitarian Engineering and Social Entrepreneurship program for the past three years.

Ms. Tara Lynn Sulewski, Pennsylvania State University, University Park

Tara Lynn Sulewski is a Ph.D. student in the Mechanical Engineering Department at Penn State and is an engineering design instructor in the School of Engineering Design, Technology, and Professional Program (SEDTAPP). She has worked with Penn State's Humanitarian Engineering and Social Entrepreneurship program for more than three years and has taken a lead on several ventures.

Dr. Amy L. Freeman, Pennsylvania State University, University Park

Amy L. Freeman is the Assistant Dean of Engineering Diversity at the Pennsylvania State University serving as an advocate for underrepresented students and women in engineering. She received her bachelor's of science degree in construction management from Washington State University and a master's of science degree in architectural engineering at Penn State. Contributing to her career path in engineering education, she also holds a Ph.D. in workforce education from Penn State with a dissertation focusing on underrepresented graduates in technical fields. She is currently serving as a Past President and executive board member of the National Association of Multicultural Engineering Program Advocates, a collaborative effort to increase the diverse technical talent in the U.S. As an educator, Freeman served in the Pennsylvania State System of Higher Education for 10 years directing student programs. During that time, she developed a wide range of retention programming for students who identified as underrepresented, international, women, or transgendered. At Penn State, she continues to provide recruitment and retention enhancement through the long standing Multicultural Engineering program and the Women in Engineering program and through cultivation of partnerships with corporations, alumni, university constituents, and organizational alliances. She has written, published, and presented research findings at national conferences and is a member of several organizations including the Women in Engineering Program Advocates Network, Society of Women Engineering, the National Society of Black Engineers, the Society of Hispanic Professional Engineers, and the American Indian Society of Engineering and Science.

She has traveled, studied, and presented internationally in Germany, Spain, Morocco, the People's Republic of China, the Republic of Korea, Kenya, Tanzania, and across the U.S. As an advocate of engineering education, she emphasizes the need to share ideas, collaborate, and learn as much as possible about others and the world around us.

Prof. Khanjan Mehta, Pennsylvania State University

Khanjan Mehta is the Director of the Humanitarian Engineering and Social Entrepreneurship (HESE) program at Penn State University. His professional interests include innovative system integration, high-tech entrepreneurship, and international social entrepreneurship. Mehta loves connecting concepts, people, computers, and devices. A basic philosophy behind his work is the convergence of disciplines, concepts, cultures, and countries to create a freer, friendlier, fairer, and more sustainable planet. He has led social ventures in Kenya, Tanzania, India, China, and other countries.

Overview of the First Year of an Innovative Science Education and Entrepreneurship Venture

Abstract

This paper describes outcomes from the first year of a multi-year multi-faceted science education reform venture based in Tanzania called iSPACES. iSPACES refers to **I**nnovation, **S**cience, **P**racticals, **A**pplication, **C**onceptualize, Design and Prototype, **E**ntrepreneurship and **S**ystems. The objectives of the iSPACES venture are to 1.) develop systems, design, and entrepreneurial thinking amongst secondary school students and their teachers, 2.) create an affordable, sustainable and replicable innovation space 3.) develop an innovative experiential science curriculum 4.) integrate the indigenous knowledge of the host country into the science education curriculum and 5.) develop a sustainable method for building prototypes using universal connectors.

These objectives were operationalized in a Humanitarian Engineering and Social Entrepreneurship (HESE) class that focuses on integrated engineering design, business strategy and implementation strategy development. Multidisciplinary student teams focused on several aspects of the project including emergent integration, innovation space design, curricular program development, indigenous knowledge integration, greenhouse design and business strategy development. The low-cost innovation space will enable students and entrepreneurs to design and create products that will add value to their daily lives and promote entrepreneurial endeavors. Universal connectors will be used in this innovation space for rapid prototyping of locally-relevant technology products. An innovative science curriculum in the form of a certificate program for secondary school science teachers was developed. This curriculum will integrate the innovation space into the formal education system and help sustain it. An affordable greenhouse was prototyped and field-tested as a compelling example of a game-changing technology that can emerge from the innovation space. This paper discusses the genesis, mechanics and logistics of the iSPACES venture and various outcomes from the first year of student engagement.

Introduction

In the last decade humanitarian engineering programs and curriculums have seen exponential growth. The growth promotes the development of a 'new type' of engineer that can think broadly, creatively, globally and sustainably [1, 2]. In addition to these pillars, humanitarian engineering curriculums promote cross-collaborative efforts and the convergence of a range of disciplines. Fundamentally multidisciplinary, humanitarian engineering also aids in increasing the recruitment and retention of underrepresented minorities due to the innovative teaching and learning strategies [3].

The Humanitarian Engineering and Social Entrepreneurship (HESE) program at Penn State engages students and faculty from various disciplines across the campus in technology-based ventures. These ventures take places in several developing countries as well as in resource-poor communities in the United States. Each venture focuses on the development of technology solutions that are technologically appropriate, environmentally benign, socially acceptable and economically sustainable. Students engage in context-driven design and develop business strategies in hands-on courses that lead to a 13-credit certificate in Engineering and Community Engagement. Faculty-led student teams travel to partnering communities in Kenya, Tanzania, India, Nicaragua and other countries every summer for field-testing and advancing the ventures towards larger dissemination and commercialization. Ventures range from a cell-phone based business networking system and a telemedicine network to solar dryers and greenhouses designed for extreme affordability [5].

iSPACES (**I**nnovation, **S**cience, **P**racticals, **A**pplication, **C**oncept, Design and Prototyping, **E**ntrepreneurship and **S**ystems) is one of several ventures within Penn State's HESE program. iSPACES originated from a request made by the Tumaini University administration to Penn State to develop an innovative science education curriculum for secondary school science teachers. During the summer of 2008, Penn State faculty visited Tumaini University to meet with faculty and administrators. The iSPACES program emerged from these discussions and was validated by various community partners. The following summer, Penn State conducted various focus groups, interviews and surveys with Tumaini faculty, administrators, students, science teachers, and school administrators. From these meetings, a concept paper was formed and approved by the Tanzania Commission for Universities (TCU). A strong focus was placed on developing an entrepreneurial curriculum to train science teachers. Over the next two years, the iSPACES project grew at Penn State as well as in Tanzania, and a stakeholders workshop was held in June of 2010. Here, specific needs, and tasks to be pursued over the first year were developed. With this framework in place, university students were engaged in Spring 2011 and the first cohort traveled to Tanzania in Summer 2012.

This paper serves to highlight the current progress made by the iSPACES venture, discuss its future goals, and identify the adaptations that will occur between year one and year two. The first section discusses the historical context of the venture and our motivations for developing this collaboration to reform Tanzania's education system. Next, in the section entitled, *iSPACES Class Structure—Subgroups*, the actual course structure and class format is described in detail. This is followed by two case-studies, one on the affordable greenhouse and the other on the universal connectors. This section serves to describe the tangible outcomes of the student trip to Tanzania. Finally, the paper concludes with a description of the future focus of the venture.

Venture Motivation

Today there are rising concerns with poor labor markets and secondary school dropout rates [6]. According to a report published by the International Labor Organization, global youth unemployment is three times higher than adult unemployment [7]. Additionally it is estimated that youth make up 43.7% of global unemployment, however, their population only accounts for 25% of the working population. There are many reasons for underemployment of youth, but in poor and post-conflict countries low quality education and training are surmised to be the primary reason [7]. This ultimately results in lost opportunities within the youth demographic and lost productivity.

Tanzania's education system has undergone numerous changes since its independence in 1961. When the country became independent, 85% of the population did not know how to read or write [9]. Therefore, the nationalist leaders set forth a goal of improving the educational system. Initially, importance was only placed on educating adults because the long-term investment with improving primary and secondary schools would not yield immediate changes to the country's economy. With time, initiatives were put in place by Julius Nyerere to improve primary schools, but secondary schools were never deemed necessary. In order to alter the system, the country began to adopt foreign curriculums to elevate the school's standards. These initiatives drastically increased the number of students in primary schools during the 1970s and 1980s. However, a lack of teachers, equipment, and communication led to Tanzanian students performing poorly on international examinations. The goal of Universal Primary Education (UPE) was achieved, but poverty reduction remained stagnant. With little benefits realized, enrollment began to declined to 60% in 2000 [10].

Motivation to increase enrollment in secondary schools was reestablished by the United Nations Millennium Development Goals (MDGs), which promoted the Education For All (EFA) movement. To meet the United Nations goals, the Tanzanian government started the Primary Education Development Programme (PEDP) in 2004. In 2010, it was reported that enrollment in primary schools was up to 95% [11]. A major problem with the current education system in Tanzania is the emphasis on teaching for standardized exams. This discourages students from remaining in the system, because they do not walk away with tangible skills. Furthermore, the current system lacks the infusion of local indigenous knowledge. At its roots, indigenous knowledge can be defined as, "what local people know and do, and what they have known and done for generations—practices that are developed through trial and error and prove flexible enough to cope with change" [12]. It is location and culture specific knowledge. Unfortunately, Tanzania's education system has barriers up against the inclusion of indigenous knowledge into the education system. In a recent case-study, Semali et al. concluded that place-based knowledge is systematically devalued within technical fields [13]. This is attributed to their formal training in rejecting hypotheses that cannot meet standards of statistical vigor. However, indigenous knowledge has intellectual merit that this school of thought often neglects.

In a science education curriculum, indigenous knowledge could describe the local flora and fauna in an ecological context. Indigenous recipes or stories passed down from elders provide local insights to the culture and the way of thinking that pervades society. Furthermore, there is a fundamental value in passing down indigenous knowledge systems in developing entrepreneurial solutions for a specific location [14]. A binary science curriculum that addresses both systematic ways of thinking and indigenous knowledge is a fundamental objective within the iSPACES venture. iSPACES is a HESE initiative that focuses on improving the effectiveness of the science education curriculum at the source, the teachers and the students. The objectives of the iSPACES project are to 1.) develop systems, design, and entrepreneurial thinking amongst secondary school students and their teachers, 2.) create an affordable, sustainable and replicable innovation space (fabrication lab) 3.) develop an innovate experiential science curriculum 4.) integrate the indigenous knowledge of the host country into the science education curriculum and 5.) develop a sustainable method for building prototypes using universal connectors.

iSPACES Class Structure-- Subgroups

These objectives were operationalized in a senior-level HESE class that focuses on integrated engineering design, business strategy and implementation strategy development. The class was broken up into various focused subgroups including emergent integration, innovation space design, curricular program development, indigenous knowledge integration, greenhouse design and business strategy development. Each group had a particular objective to accomplish, and worked independently but in coordination with other subgroups. To keep the group cohesive, each week the class met to update the entire class on each sub-group's progress. This division allowed subgroups to obtain an expertise in a particular objective—while honing communications skills, so that the venture remained as one unit. Additionally, due to the range of backgrounds within each subgroup, members were able to learn from their peers from other departments and colleges. Next, we discuss the various sub-groups and their work.

Emergent Integration

An important aspect of the iSPACES venture was the infusion of systems, design and entrepreneurial thinking into the science education curriculum. These ideas had to be fully developed by the emergent integration subgroup. First the group focused on understanding these concepts at a definition level. Then through the use of divergent thinking the group expanded the ideas to fit into the overall scope of the project. This subgroup serves as the thread connecting each sub-group back to the main objective of iSPACES, and developed the theoretical framework for the venture. Entrepreneurship and systems are the fundamental pillars of iSPACES. This subgroup was comprised of students with backgrounds in engineering, biology and economics.

Curricular Program Development

The curricular program development group included graduate students from the colleges of education and engineering. Together, the group focused on developing the overall structure of a science education curriculum which pulled upon the ideas developed through the emergent integration subgroup. Their goal was to develop the entire academic program structure/certificate program that would be implemented at Tumaini University. The group focused on the development of a workshop that could explain the background of iSPACES to current teachers in various developing communities. They also were responsible for meeting and pitching their ideas to administrators at the host university in Tanzania during the summer of 2011.

Indigenous Knowledge Integration

A fundamental objective of the science education curriculum was to permeate the indigenous knowledge of the host region into each science project or case. Promotion of indigenous knowledge, would allow the venture to be successful even after the students completed the project [14]. Therefore, the indigenous knowledge sub-group focused on developing various means to learn more about the community partners. They did this through establishing community partners both here in the US as well as in Tanzania. Students in the US conversed weekly with two HESE students who were spending the semester surveying the region in Tanzania. Through these students, the US students were able to gather information about everything from local building materials, to customs of the region. Here in the US, the indigenous knowledge subgroup sought advice from other student ventures, faculty and local Tanzanians. Furthermore, when the large group traveled during the summer, the indigenous knowledge sub-group set out to create audio-visual blogs to record the indigenous knowledge they observed, and to create an open-source document available to future ventures. Their films focused on learning more about the people's customs, traditional medicines, food preservation, and building techniques. This group was primarily responsible for documenting and cataloging information gathered on the ground, for the group to build upon for year two.

Funding

Establishing a sound business model is necessary to ensure venture sustainability. At Penn State, various models have been explored to better connect designers, implementers and end users—with the intention of achieving sustainability [15]. The funding sub-group was headed by students from the Smeal College of Business. Throughout the semester, the group focused on developing several business models, which would then further be explored with the help of community partners, once the students traveled to Tanzania. The three primary models explored were the Time-Use model, Library Model, and Revenue sharing model. Furthermore, the group worked with the various design-focused groups on developing a way to use the universal connector as a means for continuous cash flow. The universal connector will be described in detail below.

Innovation space

This group worked on the development of the physical building that could service as a facility for learning design, building, and exploring entrepreneurial principles. In year one, a group comprised of all engineering students, focused on developing a space that was cheap, manageable, and inspirational. The initial motivation for the innovation space was an idea of an extremely low-cost fabrication laboratory [16]. In developing the space, a series of questions were developed to be answered in the field:

1. How are buildings built in Tanzania?
2. What are the options for power supply?
3. What tools and materials are readily available to build with?

This group spent a significant amount of time in the field trying to fill these gaps. They met with many material suppliers and blacksmiths, and began to establish a materials database that will be made available on a website for other humanitarian engineering ventures. In addition, with the help of the greenhouse group, and motivated by the funding group, the development of a universal connector became a subtask for the innovation space group. The universal connector is described in a case-study at the end of this paper.

Greenhouse Group

The green house group was comprised of all engineers, and its main goal was to design a greenhouse that could be built by two people in two days with less than 200 dollars [17]. The greenhouse represented a pilot technology that would emerge from the iSPACES innovation space and could be used to make the science curriculum more engaging while having significant market potential as well. The idea to develop a greenhouse was primarily chosen due to the importance placed on agriculture in these regions. While in the field, the group actually built their prototype, which is currently being used by people in the region (Figure 1).

Figure 1: Green House Prototype, and in Field

Project Outcomes: Year 1

The iSPACES venture, although targeted towards Tanzania in the first year, intends to be a broad framework that can be implemented in a wide range of environments. The broad nature of this venture involves a wide range of students from varied academic backgrounds. The structure of the class described above, encourages students to champion individual tasks. The effects of this format is that students become experts in their individual tasks, and must organize their work and present each week to the rest of the class, so that everyone is aware of the overall direction the class is heading.

The emphasis on preparing and presenting your work is seen throughout the class. The whole class must present in a department-wide format to the other ventures for a midterm and final review. These review presentations are 20-30 minutes. During this time, they also receive feedback from a panel of professionals who have experience with humanitarian-based ventures. The professionals include local entrepreneurs, professors from across the university, and administration. In addition, students receive feedback from their peers who are participating in similar ventures through the HESE program. These presentations serve two functions: (1) they provide tangible dates where benchmarks must be met, and (2) they allow for student collaboration with their peers across the HESE ventures.

The multidisciplinary feel is carried over into the actual make-up of the class. In its first year the class comprised of undergraduates from business, education, engineering, and marketing majors. In addition there were graduate students with engineering and education backgrounds. For undergraduates, this is an extremely valuable setup. Younger students are able to learn about various opportunities in different majors, and older students get to learn about graduate school, and opportunities in humanitarian engineering post-graduation. Since the course is taught in the evening, graduate students have the opportunity to diversify their studies and take on leadership/mentorship positions. The program structure has also led to a high retention rate, where students remain a part of the same project for several years or explore a range of projects within HESE through their four years.

Finally, in the first year of the venture, the class collaborated with a junior English technical writing class, ENGL 202C. This class is required for all undergraduates in technical majors, and teaches discipline-specific writing strategies for scientists and engineers. Througout the semester the student's assignments were focused on the iSPACES project, including a literature review, proposal and a user manual focusing on a specific science objective. The user manuals are a "How To" guide for one application of a science concept that is culturally relevant and could potentially solve a local problem, such as a drip irrigation system or a solar dryer. An open source website was constructed for the English 202C students as a place to collaborate and edit their work. The collaborations further promoted the work of the HESE program and gave the students a unique focus for their final projects. Future collaborations with an Intro to Engineering Design course are planned for the spring of 2012, and are described in the future work section.

Notably, the work completed in Tanzania on the physical design of a Universal Connector and the construction of an affordable greenhouse are examples of the work completed in the first year. These success stories are leading the venture in the direction of focusing more on the actual innovation space. Below we highlight the work that came out of Tanzania in order to describe our next steps as a venture. The Universal Connector and the Greenhouse are examples of technologies and ventures that would emerge from the Innovation Space in the future.

Case Study: Universal Connector

In Tanzania, designs for tools and buildings are made long lasting by building them with extremely robust materials. Hammers are made of solid iron, carts are made with car tires and heavy lumber, and buildings are often left unfinished due to the high cost of reinforced concrete. The notion that tools and products can have good performance yet be robust in design is a concept rarely adapted by locals. Previous work at San Jose State University has shown that backpacks, dollies and myriad other products can be designed with the use of "universal connectors" where simple tools can be built and redesigned to build other tools in a matter of minutes [18]. Branching off the idea of utilizing simple connectors to build products and tools, SJSU's work was expanded by our team to fit a larger mold of thinking. Using only locally available materials and tools, the simplest connectors were found to be orthogonal connectors. With eight possible types, simple household items like chairs, tables, and other items with 90^o connections were easily fabricated. Some of these connectors are highlighted in Figure 2 and 3 below.

Material analysis has also shown that orthogonal connectors can be split into three different sub-categories: solid, hollow, and open (Figure 2). Each type of connector was found to be optimal for different connections. For instance, solid connectors are useful for buildings, hollow connectors are versatile and can connect solid or hollow pipes, and open connectors are useful for wood connections. Since the connections are often the weakest part of a structure, all connections were fabricated out of mild steel. The overarching goal is that these steel connectors will be compatible with every material in the local market and be useful in redesigning simple products like carts and ladders. While more research is needed to further develop the idea, the concept of standardizing building joints is a potentially profitable idea that can be used to boost entrepreneurship in developing countries.

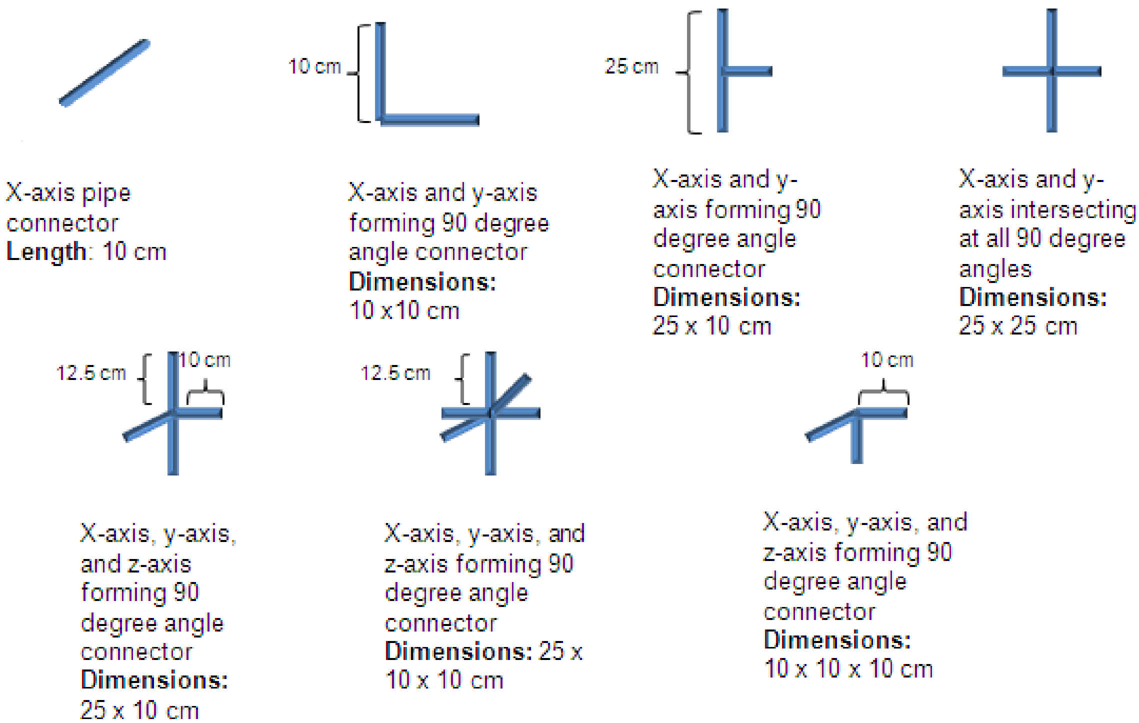

Figure 2: Solid, hollow, and open connectors.

Figure 3: Various universal connector prototypes

Case Study 2 Greenhouse

To address food security issues in Tanzania, affordable greenhouses were designed to allow farmers to grow crops in the off-season. Greenhouses allow farmers to grow vegetables and fruits year-round through mechanically controlled temperature and irrigation systems. Greenhouses can help farmers increase their yields and improve their livelihoods while reducing spoilage and furthering food security. Imported greenhouses sold in East Africa are designed for large commercial farms. They are too expensive for small-scale farmers and do not meet their needs and use preferences. While conventional greenhouses are often large in nature and built with galvanized steel and glass, our structure was designed with PVC pipes and solid rebar connectors to radically cut the cost of the structure. Two prototypes were built in Arusha, Tanzania to field-test different concepts. The prototype built at Makumira - Tumaini University utilized rice bags as the glazing which is a locally-available material that can cut the cost of the glazing in half. The second greenhouse was constructed at the Tropical Pesticide Research Institute (TPRI) which tested the optimal size of a greenhouse section. Several other design concepts emerged from the field-testing and were integrated into the final design.

Besides utilizing rebar as a solid connector, bamboo was used as a connector between the greenhouse glazing and the PVC framework. While typical greenhouses are permanent structures, the affordable greenhouse employs a modular expandable structure. Bamboo connectors facilitate greenhouse maintenance where the structure can be easily dismantled to replace parts in the future as the PVC ribs become brittle over time. The return on investment of the greenhouse is typically two crop cycles, which can be as early as four months and typically six months. Profits gained from the greenhouse can be used to expand the structure by adding more sections length-wise and accessories like drip irrigation systems.

Conclusions

The initial goals of the iSPACES venture, related to rethinking the science education curriculum and ecosystem, are complicated and require a multi-year timeline with extensive buy-in and support from our partners. Due to lack of resources we will focus our efforts on specific aspects of iSPACES that are easier to implement in the short-term and have broader applications while gradually transforming science education. One such aspect is the design of the Innovation Space. The innovation space can be utilized as an innovation center in a local community or a low-cost prototyping center for secondary schools, vocational training centers and universities in east

Africa. It can be integrated into existing university courses, or at secondary schools where students can have a space to learn shop skills and realize their entrepreneurial ambitions.

Our team is also working further on designing a set of Universal Connectors for facilitating rapid prototyping and design thinking in resource-poor environments. Six sections of a freshmen design class (EDSGN 100: Introduction to Engineering Design) explored these Universal Connectors for their first design project in the Spring 2012 semester. The project involved learning about the current state of the connectors, and brainstorming new design methods, materials, and applications. The 46 student teams came up with design ideas on how to use these connectors to solve a specific need, such as a basket/box that can be mounted on a bike and turned into a mini storefront to sell goods, or a stand that any bike can rest on to generate power. These needs were identified by course instructors with experience working in the East African context. Student teams performed two design iterations, and followed up with a building manual and final report that was handed over to the iSPACES core team. The core team is currently conducting more testing and will select a few designs to field-test in Kenya this summer. This collaboration with EDSGN 100 will provide insights into new connector designs and simple innovative applications that can be used to create a library of build options.

Several other components of the iSPACES venture are also being pursued independently. For example, we are adding finishing touches on a set of video clips with stories about indigenous approaches to community challenges in Tanzania. Another team is trying to understand and articulate the interconnectedness of design thinking, entrepreneurial thinking, and systems thinking. The goal is to leverage these philosophies for developing practical methodologies and strategies for entrepreneurial science education. The greenhouse project has been the most successful so far. The team has been awarded grants adding up to over $50,000 to refine their technology and conduct dissemination workshops in Kenya and Rwanda in Summer 2012. These workshops will target entrepreneurs and result in two kinds of enterprises – greenhouse construction businesses and agribusinesses that leverage greenhouses to grow fruits and vegetables year-round. A journal manuscript related to the design and construction of low-cost greenhouses is currently under review. In essence, while the ambitious goal of reforming science education in Tanzania has been deemed impractical in the short-term, our team is trying to build the iSPACES program brick-by-brick through every successful design, entrepreneurial venture and research endeavor. This web of related high-impact activities will ultimately lead to the emergence of innovative science education programs and allied entrepreneurial ecosystems.

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