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An Educational and Entrepreneurial Ecosystem to Actualize Technology-Based Social Ventures

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Humanitarian Engineering and Social Entrepreneurship (HESE) Program

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ABSTRACT

The Humanitarian Engineering and Social Entrepreneurship (HESE) Program engages students and faculty across Penn State in the rigorous research, design, field-testing, and launch of technology-based social enterprises that address global development challenges. HESE ventures are embedded in a series of five courses that integrate learning, research, and entrepreneurial engagement. The goal is to educate globally-engaged problem solvers who can create sustainable and scalable value for partnering communities, while simultaneously generating and disseminating new knowledge and lessons learned. This article describes the genesis, foundational philosophies, programmatic learning outcomes, and course mechanics of the HESE Program. The eplum model of student engagement, which embeds HESE sub-projects into regular credit classes and provides rigorous yet non-travel-based experiences to a cross section of students, is discussed. A mixed methods approach is utilized to examine the effectiveness and impact of the eplum curricular model on student learning, specifically in the areas of global awareness, multidisciplinary teamwork, and entrepreneurship education. The entrepreneurial and research outcomes of the program are summarized with a culminating discussion on the emergence of an educational and entrepreneurial ecosystem that has proved pivotal to actualize the ventures and achieve sustainable impact.



Key Words: Humanitarian Engineering, Social Entrepreneurship, Service Learning, International Development, Social Innovation

INTRODUCTION

The Engineer of 2020, as described by The National Academy of Engineering, is a leader in the movement towards informed and economically sustainable development [1]. Engineering educators are charged with the task of preparing students with a strong foundation and knowledge of innovative technologies that advance society. In response, engineering education has increasingly emphasized experiential education and professional skill development. Upon entering the workplace, graduates are expected to be technically proficient as well as educated citizens at home with societal concerns. Hence, universities are integrating concepts of entrepreneurship, societal implications, global contextualization, ethics, cultural sensitivity, multidisciplinary teamwork, and engaged scholarship into regular coursework.

At the same time, almost half the world's population lives on less than \$2.50 per day and millions of people lack access to food, clean water, sanitation, energy, and basic healthcare. Paul Polak, the founder of International Development Enterprises, estimates that 90% of the design efforts in the world are directed towards 10% of the world's population. Several academic programs and co-curricular student clubs have emerged to reverse this trend by addressing the needs of developing communities in the United States and abroad. Academic programs of this type include Humanitarian Engineering at the Colorado School of Mines, Global Resolve at Arizona State University, D-Lab at MIT, Design for Extreme Affordability at Stanford University, Development Engineering program at the University of California, Berkeley, and the Mortenson Center in Engineering for Developing Communities at the University of Colorado, Boulder. Extra-curricular student clubs and professional organizations include Engineers without Borders, Engineers for a Sustainable World, Bridges to Prosperity, and Global Brigades, amongst others.

Along similar lines, the Humanitarian Engineering and Social Entrepreneurship (HESE) Program engages students and faculty across Penn State in the rigorous research, design, field-testing, and launch of technology-based social enterprises (for a two-minute introductory video, see <http://www.youtube.com/watch?v=fPOGKqHm9nA>). HESE ventures are multi-year endeavors that range from low-cost greenhouses and solar food dryers to telemedicine systems, ruggedized biomedical devices, cell-phone applications, and informal education systems. HESE espouses the fundamental philosophies of Empathy, Equity, and Ecosystems to create a vibrant and emergent framework for students, faculty, and diverse partners to come together and truly collaborate to develop sustainable and scalable solutions. Sustainability, in this



context, refers to the notion that solutions must be technologically appropriate, socially acceptable, environmentally benign, and economically sustainable. The genesis of most projects can be traced back to requests made by partners in developing countries. However, rather than striving to solve the partners' specific problem(s), the HESE approach is to co-create products and services with diverse stakeholders and commercialize them to benefit larger populations. Ideas, presentations, and prototypes do not solve problems; the real challenge is implementation, assessment, and fast-paced pivoting. The challenge is execution - getting the job done - launching and sustaining social ventures. HESE's focus on execution and sustainable impact drives the courses, pedagogies, and program operations.

This article begins with an overview of social entrepreneurship and the importance of its integration with humanitarian engineering before describing the emergence of the HESE program at Penn State. Program mechanics and the academic model that engages students and faculty mentors across campus in various formal and informal ways is presented next. The 'eplum model of student engagement,' engages students in diverse ways such as honors theses, focused courses, projects embedded within other courses, commissioned assignments, and volunteer efforts. This approach expands opportunities for students to participate in social entrepreneurial ventures while being mindful of their time and credit constraints. The objective of this model, and the HESE program, is the convergence of disciplines, concepts, cultures, and countries towards a freer, fairer, friendlier and more sustainable planet. This model reflects the philosophy of "E Pluribus Unum", the United States motto that translates to "out of many, one." Hence, we call this model 'eplum', a portmanteau from E Pluribus Unum. The eplum model is an extremely lean and scalable approach to weave innovation, global awareness and engagement, multidisciplinary teamwork, and social entrepreneurship education into a number of courses to reach a larger number of students and build pipelines into the program. The humanitarian focus of the ventures serves as a motivating factor for students and faculty to develop the technical and professional skills necessary to prepare students for modern engineering practice and metamorphose them into social problem-solvers and entrepreneurial global citizens.

A mixed methods approach is utilized to examine the effectiveness and impact of the HESE program, using both qualitative and quantitative methods of data collection and analysis. The specific research question that guided the evaluation is: How does participation in the HESE program impact students' perceptions of their skills related to global awareness and engagement, multidisciplinary teamwork, and social entrepreneurship? Data collection strategies include an online survey, student focus groups, and examination of students' responses to a course blog. HESE students are expected to work on original publishable research projects that directly inform the entrepreneurial ventures. This article culminates with a discussion of the entrepreneurial and research outcomes from the program and how the program has developed an educational and entrepreneurial ecosystem to actualize ventures and effect larger social impact.

**THE ADVENT OF SOCIAL ENTREPRENEURSHIP**

Over the past two decades, academic programs focused on entrepreneurship have grown rapidly across the United States and around the world [2] [3]. Such programs strive to develop an entrepreneurial mindset among students and also encourage them to become entrepreneurs. Entrepreneurship is largely considered a driving force for national economic growth and systemic innovation. While only a small fraction of students will become entrepreneurs, an entrepreneurial mindset, a way of thinking and doing that demonstrates leadership, initiative, innovation, ownership, responsibility – creating something new and getting things done – can help students be successful in any pursuit. Universities across the US have proactively developed academic programs and immersive experiences with the purpose of educating aspiring entrepreneurs. While entrepreneurship education takes a strong foothold in academia, concurrent foci on global sustainability and public scholarship are defining entrepreneurship in a broader and more inclusive manner. The United Nations labeled 2005 – 2014 as the “Decade of Education for Sustainable Development” and elevated it to the most important educational goal of this century [4]. Service-learning is one avenue through which universities are engaging students in real-world projects that further sustainable development [5][6].

Engineering Design and Humanitarian Engineering are two areas in which service-learning has been particularly effective for institutions and communities [7] [8] [9]. Humanitarian engineering may be defined as research and design under constraints to directly improve the wellbeing of marginalized communities [10]. The most distinctive aspect of this type of engineering is its target audience, i.e., those that might be classified as marginalized, as well as its focus on actually implementing sustainable solutions to benefit those individuals and their communities. Designing solutions for complex problems in resource-constrained contexts necessitates systems thinking and a trans-disciplinary approach to develop innovative and realistic solutions. Some such endeavors, like Engineering Projects in Community Service (EPICS), employ the pedagogy of service-learning to benefit local communities [11]. At the same time, a growing number of academic programs and co-curricular clubs (e.g. Engineers Without Borders) engage students in the development and implementation of technologies for resource-constrained environments in developing countries. The aim is generally two-fold: to provide students with valuable educational experiences and to address the needs of marginalized communities at the so-called base-of-the-pyramid (BoP).

While such endeavors are usually well-meaning, creatively designed, and enthusiastically deployed, they do not necessarily result in a sustainable impact. This is due, in part, to prioritizing immediate educational experiences for students over long-term sustainable impact for the partnering communities. The primary challenges for development projects are not on the engineering side, but are related to the cultural, social, ethical, and business planning aspects, mostly during project



implementation [12]. See <https://www.youtube.com/watch?v=vYuckWTNsnw> The key challenges in descending order of importance are designing and evaluating appropriate systems (as opposed to individual technology products), ensuring equity between the stakeholders, scaling ventures, identifying marginalized stakeholders and engaging them in the project, understanding and managing power dynamics and privilege systems within communities, identifying and incentivizing champions, public relations, and business planning with non-cash equity. In essence, while the development of appropriate technologies from a systems perspective is important, getting the technology in the hands of the people and effecting social change is a larger and more complex challenge.

Social entrepreneurship extends humanitarian engineering efforts through the development and implementation of sustainable business models that benefit the partnering communities, organizations and larger society [13]. Entrepreneurs create value by “shifting economic resources out of an area of lower and into an area of higher productivity and greater yield” [14]. If the primary objective of sustainable value creation is positive social change, the entrepreneur can be categorized as a social entrepreneur. Venture sustainability and its ability to create social change on a larger scale are essential. Metaphorically, while conventional entrepreneurs might pursue the creation of multi-million dollar enterprises, social entrepreneurs strive to create multi-million smile enterprises while understanding that their ability to expand their social returns bears a dynamic interdependence with their economic bottom line. Social entrepreneurs prioritize and measure the social returns accrued by their innovative products and services while remaining financially self-sustainable.

If the goal is to actually launch sustainable social enterprises, university-based educational programs cannot design appropriate technologies, develop business plans, and implement solutions in a linear piecemeal fashion. A collaborative and integrated “triple helix” approach of systems design, business strategy, and implementation strategy development is essential. Execution, the process of operationalizing the design and the business/implementation strategies, is everything [15]. This integrated design and implementation process encompasses conceptualization, validation, design, field-testing, implementation, and evaluation all done in a highly-iterative fashion. There are several successful models for the integration of service-learning projects into engineering courses, especially design-centric ones [5, 16]. The rigorous integration of an entrepreneurial approach into humanitarian engineering endeavors has the potential to transform a service-learning program that focuses on low-impact service activities to high-impact social enterprises. Several universities have broken away from service programs where students make aspirational presentations, paint walls at schools and install solar panels at orphanages in an ad-hoc fashion, to designing and launching sustainable and scalable ventures focused on solar lanterns, affordable greenhouses, biomedical devices and other technologies that sustainably address development challenges.



Identifying and Aligning Educational Outcomes with the Academic Ecosystem

The literature is sparse on the knowledge base and competencies of successful social entrepreneurs, and the educational regimens that must be developed to nurture them. The approach adopted by the HESE program draws primarily from the first author’s experiences effecting social change through technology-based enterprises in developing communities over the past decade. Table 1 summarizes the educational outcomes deemed essential to the praxis of humanitarian engineering and social entrepreneurship. While the outcomes were derived from actual needs, they were aligned with the educational mission of Penn State’s College of Engineering. These program outcomes are aligned with the Penn State World Class Engineer attributes: Solidly Grounded, Technically Broad, Globally Engaged, Ethical, Innovative, Excellent Collaborators, and Visionary Leaders. The HESE programmatic outcomes also meet several of ABET engineering program objectives a-k such as the ability to work in multidisciplinary teams, ability to communicate effectively in technical reports and orally, demonstrate independent learning to solve problems, ability to design systems, components and processes within realistic constraints, and understand the ethical implications and responsibilities of their work. For a comprehensive discussion on the education of Humanitarian Engineers and Social Entrepreneurs, see *Convergence: Philosophies and Pedagogies for Developing the Next Generation of Humanitarian Engineers and Social Entrepreneurs* [17].

HESE Content Area	Programmatic Learning Outcomes
# Class content and experiences focus on:	At the successful conclusion of this program, students should be able to:
1 Human Centered Design Context-Driven Design	Design products and services for marginalized populations in resource-constrained environments. The products must be technologically appropriate, environmentally benign, socially acceptable, and economically sustainable.
2 Social Entrepreneurship	Develop and implement business models and execution strategies to actualize technology-based social ventures.
3 Global Engagement	Collaborate with individuals from different countries, cultures, worldviews, and epistemological traditions to create sustainable value.
4 Systems Thinking	Apply systems thinking to conceptualize, implement and assess social ventures in chaotic resource-constrained environments.
5 Ethical Decision-making	Determine the most appropriate and ethical solutions for specific real-world situations after careful consideration of the most salient facts, stakeholders, consequences, duties, virtues/underlying values, and relationships.
6 Multidisciplinary Teamwork	Function effectively in multi-disciplinary cross-functional teams that include students and mentors from various colleges and representatives from partnering organizations.
7 Communication	Communicate complex ideas to a wide swath of stakeholders in a concise and precise fashion. There is an emphasis on grassroots diplomacy: articulating ideas in a non-confrontational, non-controversial, and polite manner to advance the venture while strengthening relationships.
8 Scholarly Research and Publication	Develop publication-quality manuscripts based on the findings of IRB-approved research endeavors.

Table 1. Educational Outcomes for Technology-based Social Entrepreneurship.



HESE is a field that needs multidisciplinary engagement, and hence, it is crucial to demonstrate the relevance and importance of these educational outcomes to other colleges. We examined the strategic plans of 14 colleges at Penn State, as well as the overall university strategic plan, for the explicit mention of ten themes that occur most frequently in the discourse around undergraduate learning. The themes (and the number of times they were mentioned in the strategic plans) were student success through active learning (15), fostering diversity (15), global awareness and engagement (14), interdisciplinary engagement (14), innovation (14), public scholarship (10), ethics (12), undergraduate research (10), sustainability (11), and entrepreneurship (8). Entrepreneurship was explicitly stated as a strategic thrust by only half of the colleges. However, active learning, fostering diversity, global engagement, multidisciplinary teamwork and other themes are nearly universal, representing an opportunity to present HESE courses and ventures differently. For example, social entrepreneurship can easily be understood and accepted when presented as public scholarship with long-term impact, or a mechanism for multidisciplinary active learning on an innovative project.

The HESE program exists alongside similar programs in Engineering Entrepreneurship (US-centric), Engineering Leadership Development, Engineering Design, Civic and Community Engagement, and Sustainability Leadership. These programs have their own focal areas but share common goals and programmatic learning outcomes. However, students often find it difficult to integrate the necessary coursework for HESE and similar programs into their dense schedules. Similarly, common approaches to enhancing students' global competencies and developing entrepreneurial mindsets reach only a limited number of students - those who can afford them. Rising travel costs and risk management issues hinder the growth of such opportunities, especially to emerging economies in Africa and Asia. There is a need to expand these global educational experiences from a select few to the vast majority of students. Embedding engagement opportunities into regular credit classes and providing rigorous, yet non-travel-based experiences, is essential to scale student engagement and interest in global social entrepreneurship. Such mechanisms can expose students to entrepreneurship, build their confidence, and serve as a pipeline to more focused, rigorous, and extremely demanding academic programs like HESE that prioritize the launch of entrepreneurial ventures. This reality directly influenced the academic engagement model described in this article.

Rationale and Foundation of the Educational Outcomes

Globalization has increased the interconnectedness between nations and peoples of the world. It has put increased pressure on educational institutions to prepare students for life in an increasingly connected and borderless world. The engineering profession is likely one of the most global professions with international design teams developing technologies for international markets. Engineers must be prepared to engage and thrive in this global workplace, face the challenges, and leverage



the unprecedented opportunities in this brave new world. Accordingly, across the United States, there is a growing trend towards internationalizing the engineering curriculum and fostering global engagement [18].

According to Merryfield, the eight elements of global education are: human beliefs and values, global systems, global issues and problems, cross-cultural understanding, awareness of human choices, global history, acquisition of indigenous knowledge, and development of analytical, evaluative and participatory skills education [19]. Among these, the emphasis on indigenous knowledge and analytical, evaluative, and participatory skills are an addition to the Hanvey and Case definitions [20] [21]. These facets of global awareness are relevant to HESE because it is essential for students to understand contemporary challenges facing impoverished communities in developing countries, and the factors which impact technology design, implementation, and commercialization. Such factors include, but are not limited to, social and cultural norms, community dynamics and privilege systems, and indigenous knowledge systems. Students need to be aware of, and appreciate, cultural diversity, individual differences, and different worldviews and value systems.

For HESE teams, the key to success is integrated design, business, and implementation strategy development with a frugal innovation mindset. Designing solutions for complex problems in resource-constrained settings calls for systems thinking and a trans-disciplinary approach to develop innovative and realistic solutions. To develop and launch social enterprises, students have to work with a large network of partners and collaborators - communities, industry, tourists, community-based organizations, non-governmental organizations, faith-based organizations, governmental agencies, and UN agencies. These diverse entities provide the capital and enable synergies that accelerate the shared quest for sustainable solutions. Social entrepreneurs need to be highly collaborative and especially effective at bringing diverse parties to the table, identifying common ground, and taking joint action. The ability to develop a network of relationships, and to recruit, lead, and inspire staff, partners, and volunteers is important. Social entrepreneurship often demands establishing credibility across multiple constituencies, and the ability to mobilize support within those constituencies. Students need to be prepared to communicate and effectively function in this extremely multicultural context.

While engaging with these diverse partners, students are likely to experience ego and community tensions and dynamics. They might get asked for grease payments or be propositioned for dowry. They might experience conflict or observe other groups, or their own team, compromise the core tenet of self-determination. Students need to empathize with the various stakeholders and in the backdrop of the facts and the cultural context, make ethical decisions related to the venture. The student entrepreneurs do not consider themselves to be diplomats in the traditional sense of the word even though they frequently encounter conflict in the course of their activities. Students need to learn grassroots diplomacy: the complicated and delicate art of working in a radically different cultural context in a



harmonious and effective manner to catalyze social change. In order to succeed, teams need to negotiate amongst themselves (and their local partners) on whether a certain design goal (such as safety requirements) will be met in the physical hardware design; in software (for cell phone/computer-based systems); through the business strategy by focusing on a specific market; the implementation process; the legal organization and user agreements; or stakeholder education. This negotiation requires deep understanding of the context, the users, and all aspects of the venture, and epitomizes the praxis of convergence and systems thinking to create an emergent learning environment and high-potential entrepreneurial venture.

This form of multidisciplinary engagement aligns with the core tenets of teamwork: communication, team orientation, team leadership, monitoring, feedback, backup, and coordination [22]. In addition, other important conditions for successful multidisciplinary teamwork include: respect for, and understanding of, other team members, open-mindedness to diverse views and opinions, motivation to think critically, a safe environment, understanding of sources of conflict and development of negotiation and conflict resolution skills, and cultural awareness [23]. HESE students work on their ventures with peers from radically diverse disciplines. Through this teamwork experience, students are expected to 1) improve their communication skills in terms of intra-professional communication; 2) become more open-minded to diverse views and approaches brought by team and community members from different disciplines and epistemological traditions; 3) build trust towards team members who come from different disciplines and be willing to seek and provide feedback from team members outside of one's own area; 4) be more eager to learn about theories and concepts in other disciplines and be able to integrate concepts in other disciplines into one's own work; and 5) improve their skills of conflict resolution and negotiation with team members from other disciplines.

The convergence of participatory research and social entrepreneurship uncovers and emphasizes the community's self-determined needs, resources, and aspirations and helps leverage them to create sustainable value. Engaging students in formal institution-approved research endeavors strengthens the venture while adding rigor to the students' education by further developing their entrepreneurial mindset and venture creation competencies. Scholarly research can lead to publications in refereed journals and conference proceedings and serve as tangible outputs for the students while simultaneously advancing the cumulative knowledge in the field. The objective of such research endeavors is not necessarily to fill a gap in the literature or prove a hypothesis. Rather, the goal is to democratize knowledge by informing and inspiring other innovators so that we can collectively stand on the 'shoulders of giants.' Advancing scholarship in the theory and praxis of technology-based social entrepreneurship is essential in order to mainstream this emerging field and engage more faculty and students with the ultimate objective of fostering social enterprise and effect sustainable impact.

**HUMANITARIAN ENGINEERING AND SOCIAL ENTREPRENEURSHIP AT PENN STATE**

The Humanitarian Engineering and Social Entrepreneurship (HESE) program at Penn State evolved from students working together as part of a learning community through a series of course-based efforts, into a 12.5-credit certificate program in Engineering and Community Engagement and the Social Entrepreneurship specialization in the intercollegiate minor in Entrepreneurship and Innovation. Students undertake technology-based social ventures in conjunction with partnering academic and community organizations. These are multi-year ventures that are tightly integrated into students' academics. Students work in cross-functional teams on the design, testing, and commercial implementation of their ventures. A series of courses offers multi-disciplinary real-world integrated engineering research and design experience; it ranges from problem formulation through venture scale-up and performance assessment, depending on where the particular venture is in its lifecycle.

The HESE program is based on the fundamental philosophy that the answer to wicked global challenges is through a convergence of 1) concepts, disciplines, and epistemologies; 2) cultures and countries; 3) learning, research, and engagement; and 4) professional partners that share a common vision and purpose. Building long-term relationships with multi-sectoral partners and leveraging indigenous knowledge to foster developmental entrepreneurship form the foundation of all initiatives. While the program practices the pedagogy of Service-Learning to further the social ventures, the word "service" is never used. The focus of the program is not to "serve" anyone but to build equitable reciprocal relationships with diverse partners, and work shoulder-to-shoulder with them to develop technologies and launch entrepreneurial ventures that prioritize the social returns while being economically sustainable. There is a recognition among students and faculty that they typically gain more from their engagement than what they give back to the partnering entities. Empathy, equity, and ecosystems form the cornerstones of this philosophy of entrepreneurial engagement. This sentiment is captured by a quote from the legendary social entrepreneur, Dr. Govindappa Venkataswamy, the founder of the Aravind Eye Hospital in India:

"When we grow in spiritual consciousness, we identify ourselves with all there is in the world. Then there can be no exploitation. It is ourselves we are helping. It is ourselves we are healing."

Subject matter experts from industry and the professional world, as well as local knowledge experts, advise and mentor the venture teams. HESE teams are largely based on the concept of E-teams (multidisciplinary group of students, faculty, and mentors working together to bring an invention to market) championed by VentureWell [formerly known as the National Collegiate Inventors and Innovators Alliance (NCIIA)]. HESE has developed long-term relationships with communities, industry,



government, non-profit, faith-based, and UN partners in Kenya, Rwanda, Tanzania, India, Cameroon, Sierra Leone, Mozambique, and other countries. Ventures emerge from, and are supported by, these strong relationships that have been nurtured over several years. The ventures are intertwined with HESE courses, and aspects of the ventures are integrated into a wide range of courses by way of the eplum model. Approximately 100 students participate in the core course offerings every year, with about 400 students engaged in peripheral course and co-curricular activities, and 200 others engaged in extra-curricular activities. While half the students are engineering students, the other half come from every other college across campus. The majority of the students are upper-division students with about 15% graduate students, and 15% lower-division students. Over half the students are women who participate for a multiplicity of reasons including a) becoming a global professional; b) making a difference; and c) applying theory learned in school to address a problem [24].

Ongoing HESE Ventures

HESE ventures span several domain areas and their frameworks are designed to attract students from every single major across campus. The ventures have received funding from various agencies including VentureWell, USAID, Clinton Global Initiative University Program, IJSLE-Carter Academic Service Award, EPA P3 program, and private sponsors. The funds directly support the ventures but are not intended to support student travel. HESE ventures that were active at the time when this study was conducted are summarized in this section. Several of these ventures are ongoing while others have been completed or phased out and new ventures initiated.

Mashavu: Networked Health Solutions

Mashavu is a telemedicine system that connects medical professionals in developing countries with rural communities through the use of innovative smartphone-based technologies. Mashavu operators collect a patient's medical history and vitals and send them to a healthcare professional who responds with a recommended course of action within twenty minutes. The operators charge customers a small fee per consultation, thereby making the venture economically sustainable [25] [26]. Student teams also design affordable biomedical devices ranging from ruggedized pulse oximeters to inkjet-printed diagnostic test strips for detecting infections.

WishVast: Building Trust and Social Capital using Cellphones

WishVast is a cell-phone-based business networking system that harnesses the pervasiveness of cellphones to optimize resource utilization and facilitate people-to-people trade, with the ultimate goal of alleviating poverty. WishVast allows its users to join groups of local relevance to exchange information, meet new people based on shared interests, and build trusting relationships [27][28].

***EssentialDesign: Affordable Technologies***

EssentialDesign projects focus on the development of affordable infrastructure technologies. These include projects related to housing, water and wastewater systems, energy, and agricultural systems. Current ventures focus on food security and include low-cost greenhouses, solar food dryers, rainwater harvesting systems, and ceramic water filters [29][30].

iSPACES: Rethinking Science Education + Design of Innovation Space

The iSPACES venture, based in Tanzania, focuses on the development of a science education program based on the tenets of science, systems and entrepreneurship [31][32]. An integral aspect of this program is the design of an affordable and sustainable innovation space where people from various walks of life can converge to rapidly prototype innovative products that meet their unique needs and preferences [33].

Project Prerana: Rural Supply Chains + Educational Systems to Empower Women

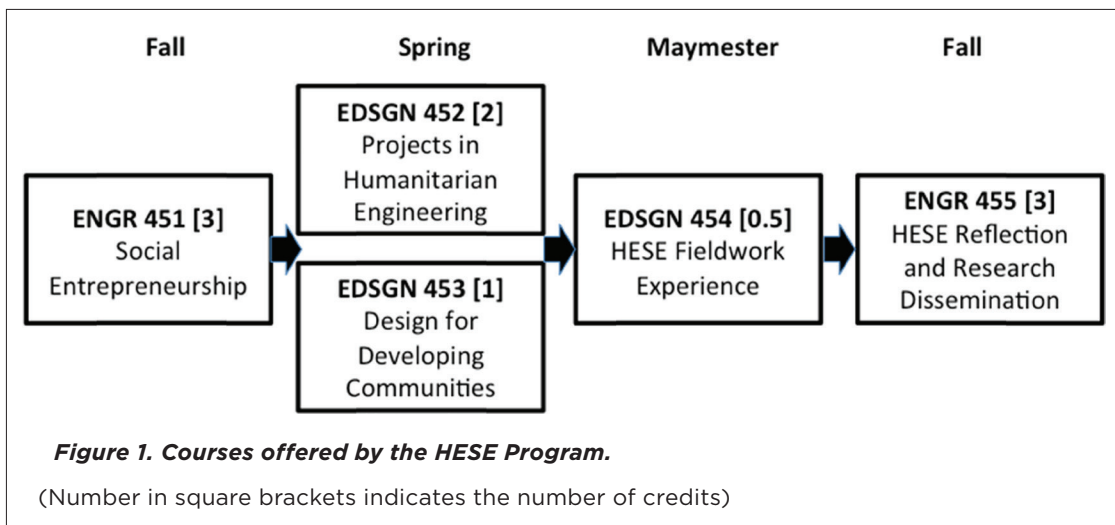
Prerana leverages opportunities for social innovation that emerge at the dynamic intersection of informal education systems and rural supply chains in the developing world. This multi-level information and communication technology (ICT) platform can be used to facilitate iterative learning where the knowledge emanates from the participants and their indigenous ways of knowing and doing. Interaction at all levels provides agency to the participants while serving as a means for the long-term preservation of local knowledge [34].

HESE Projects in K-12 Education

Engineering students serve as effective partners, role models and mentors to K-12 teachers and their students. HESE students work on technology with K-12 teachers, students and retirement communities with the goal of motivating students to use their mathematics, science, business, and social studies skills to build functional bench-top agricultural systems for various customers. These projects have now been discontinued.

HESE Academic Structure

This section discusses the academic offerings of the HESE program. As opposed to students coming up with new project ideas in a class, ventures undertaken in the courses are multi-year endeavors that have emerged organically from engagement with developing communities. These venture ideas are validated and developed further by venture teams, until they succeed, fail, or are deemed not worth pursuing further. In our experience, it takes between 3-5 years for a venture to mature. Most of the intellectual property is published so as to place it in the public domain. Students have the option of retaining their intellectual property and pursuing the ventures themselves. However, it is difficult for



most students to make a multi-year commitment after graduation to their ventures. Faculty-led multi-year ventures are an alternate solution to provide students with immersive frameworks for learning, research, and entrepreneurial engagement, while advancing ventures towards large-scale dissemination.

HESE classes (Figure 1) are experiential learning activities with an open environment nurtured by mutual respect between the instructors and students. The prerequisite for the courses is fifth semester standing and lower division students with community engagement experience are routinely admitted. Despite bringing together freshman through PhD candidates from across campus, the classroom is viewed as an even playing field where students and faculty come to break down barriers and innovate. This helps to foster a deep learning and engagement culture where students are unafraid to take risks and make mistakes. Fast failure is encouraged and the goal of sustainable impact is reinforced throughout the various learning activities. A deeper perspective on the team culture championed by the HESE program can be obtained from another article titled “*Reflections on Multidisciplinary Teamwork: From Experience to Impact.*” [35]

Summary of Courses

ENGR 451 [3]: Social Entrepreneurship

Website: www.hese.psu.edu

This course provides students a conceptual framework of social entrepreneurship in the global arena. It explores social challenges and solutions with a systems thinking approach with the help of case studies of successful and failed social ventures from diverse world regions and sectors such as healthcare, energy, food, and education. Students work in multi-disciplinary teams to develop business models and implementation strategies for technology-based social ventures.

***EDSGN 452 [2]: Projects in Humanitarian Engineering***

Several projects linked through www.hese.psu.edu

Students undertake technology-based social ventures in cooperation with partnering organizations. There are several sections of this course that focus on ventures in various countries. These ventures change from year to year. Students work in cross-functional teams on the design, testing and commercialization or implementation aspects of their ventures. Students are required to concurrently register for the EDSGN 453 class.

EDSGN 453 [1]: Design for Developing Communities

Website: www.hese.psu.edu

This seminar course grounds students in the basics of humanitarian engineering, user-centered design for extreme affordability, social entrepreneurship, systems thinking, travel and fieldwork, ethical decision-making and related issues. Students can take the seminar course by itself but the vast majority also enroll in the EDSGN 452 course.

EDSGN 454 [0.5]: HESE Field Experience

21-minute TV Program: <https://www.youtube.com/watch?v=8cORUmLPpTw>

The HESE Field Experience is a hands-on integrated learning, research, and entrepreneurial engagement experience. Students travel to project site(s) for about three weeks in the shortened May semester to conduct field-testing of their technologies, implement their business models, and gather data for their research projects. They work very closely with community members and various partnering agencies during that time.

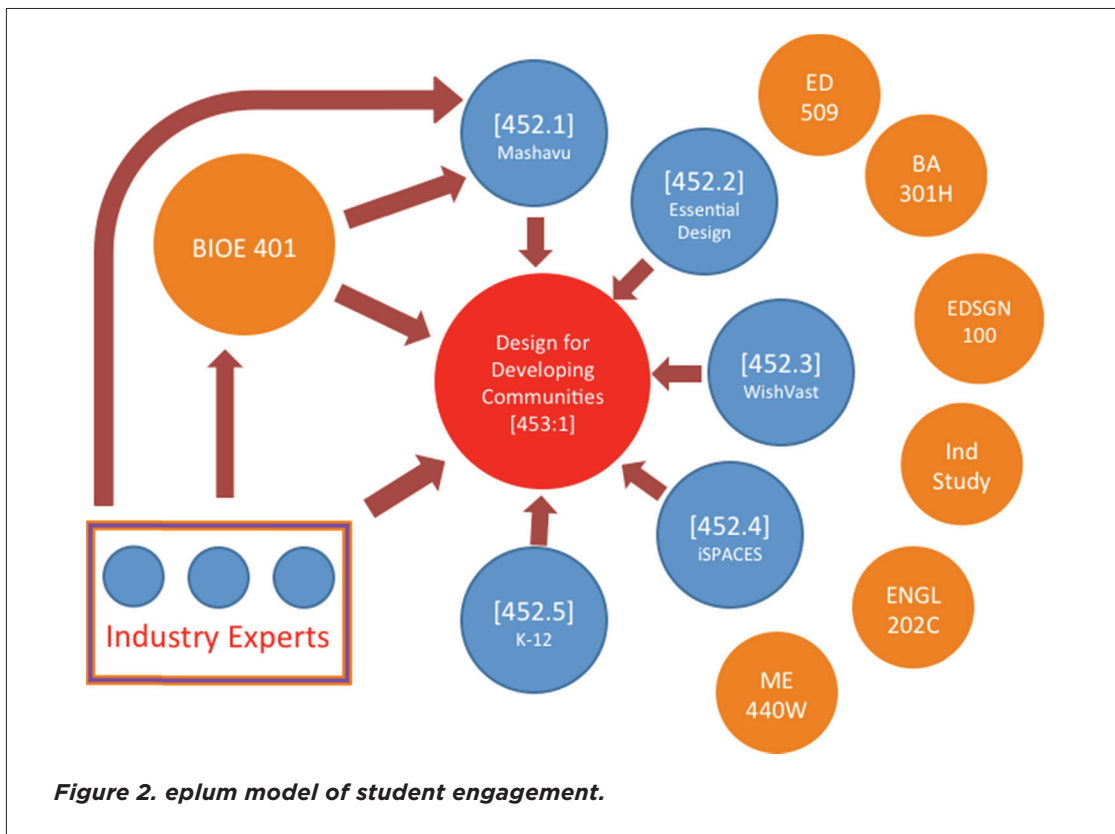
ENGR 455 [3]: HESE Reflection and Research Dissemination

Website: www.hese.psu.edu

This course provides students an opportunity to reflect and build upon their experiences following fieldwork. There are three themes in this course. The ethical decision-making theme explores the ethical intricacies of conducting research and advancing entrepreneurial ventures in developing communities. The grassroots diplomacy theme delves into the complicated and delicate art of working with in-country partners in a harmonious and effective manner. The research dissemination theme provides students with just-in-time knowledge necessary for developing their research manuscripts for eventual publication in peer-reviewed journals and conferences.

eplum Model of Student Engagement

The eplum model (Figure 2) engages students and faculty mentors from various colleges across campus. Core design teams form the nucleus of the venture and are responsible for system



integration and developing the business and implementation strategies. The core teams are housed in the EDSGN 452 class. Every venture has its own section. The course is open to undergraduate and graduate students from all disciplines. For example, the validation team for Mashavu consisted of students from Chemical Engineering, Bio behavioral Health, Women's Studies, Kinesiology, Political Science, and Journalism. Over the last four years, over 500 students from 46 majors across 12 colleges have contributed to the Mashavu venture. All students in the core teams also enroll for the common one-credit EDSGN 453 seminar class. The weekly seminar is streamed live (and is available on-demand) for students at other campuses, counterparts in developing countries, and industry professionals mentoring the teams.

Besides the core teams housed in the EDSGN 452 classes, a number of other courses participate in the various ventures. Table 2 shows the various forms and levels of engagement and the corresponding classes. The levels of engagement include:

1. **Travel to Project Site for Fieldwork:** Students who have participated in the various courses travel to the project site for three weeks at the end of the spring semester to advance their ventures. Students are required to sign up for the EDSGN 454 course.



An Educational and Entrepreneurial Ecosystem to Actualize
Technology-Based Social Ventures

Form of Engagement	Role in the venture	Classes involved	Students per year
HESE Fellows	Championing ventures on the ground for 4-6 months		~4
ENTI Minor; Social Entrepreneurship cluster	A subset of students enrolled in the courses		~10
ECE Certificate	A subset of the students enrolled in the courses		~15
Global travel for fieldwork	Fieldwork to advance ventures	EDSGN 454	~50
Honors thesis	Research / Design		~5
Dedicated courses	Core Teams for the various ventures	EDSGN 452 Multiple Sections	~60
Venture integrated into the course	Biomedical Device Design	BIOE 401	~60
	Systems Design	EDSGN 597C	~12
	Introduction to Engineering Design	EDSGN 100	~200
Course commissioned assignment	Detailed Business Planning	BA 301H	~5
	Literature Review	CED 230	~10
	Documentation / User Manuals	ENGL 202C	~70
Independent study	All Ventures: various tasks	Various X96 & X94	~5
Volunteer Effort	All Ventures: various tasks	None	~10

Legend:
 ENTI Minor / Social Entrepreneurship Cluster: Intercollegiate Minor in Entrepreneurship and Innovation
 ECE Certificate: 12.5-credit certificate in Engineering and Community Engagement
 EDSGN 454: HESE Fieldwork Experience
 EDSGN 452: Projects in Humanitarian Engineering
 EDSGN 597C: Systems Design
 BIOE 401: Introduction to Bioengineering Research and Design
 CED 230: Development Issues in the Global Context
 BA 301H: Finance (Business Planning)
 ENGL 202C: Technical Writing
 Various X96: Independent Study credits
 Various X94: Research Project credits

Table 2. Forms of engagement in the eplum model.
 (*The actual courses and number of students vary from semester to semester. E.g. in Spring 2015, ~1,200 were engaged with this model)

- ECE Certificate:** Students can take the entire sequence of courses that constitute the 12.5-credit certificate program in Engineering and Community Engagement. The 9.5 credits offered by HESE form the Social Entrepreneurship cluster in the university-wide minor in Entrepreneurship and Innovation.
- Honors Thesis:** Schreyer Honors Scholars and students majoring in Engineering Science are required to complete an undergraduate thesis. Students working on aspects of the ventures as part of their thesis may be enrolled in some of the courses as well. Generally work on the thesis is done over multiple semesters, which facilitates the continuity of ventures.
- Dedicated Course:** The Projects in Humanitarian Engineering (EDSGN 452) course, described earlier, is focused on the integrated design, business strategy, and implementation strategy



development for the venture. The first few weeks of the semester are typically spent on understanding the social and economic objectives of the ventures, prior work, and lessons learned. The goals and milestones for the next design cycle are established by the faculty and lead students with inputs from the Fellows and collaborators. Students then formulate their plan of action to realize the goals and work collaboratively for the rest of the semester to develop the necessary deliverables. The deliverables might include technology prototypes, software programs, websites, user manuals, text-based or multimedia educational materials, policy documents, test plans, and assessment instruments. The various sections of the course correspond to diverse overarching ventures and are structured differently. While some of the sections have large teams working on different aspects of a complex venture (e.g. Mashavu Telemedicine System), other classes have multiple teams working on diverse ventures related to an overarching topic (e.g. food security or science education). Students in the core teams then interact with the peripheral courses as needed.

5. **Venture integrated into an entire course:** A significant aspect of a social venture is integrated into a course as a semester-long project. For example, a mandatory junior-level bioengineering class (BIOE 401: Introduction to Bioengineering Research and Design) with ~90 students is working on the design of inexpensive biomedical devices for the Mashavu telemedicine system. Student teams with six members employ rigorous design methodologies to design the devices. They construct and test the prototypes and develop IRB protocols for conducting field-testing at the project site. At least one student from each of the teams in this class serves as the context lead and attends the EDSGN 453 seminar class. Another example is a graduate-level Engineering Design class on Systems Design (EDSGN 597C) that conducted the systems design for the Mashavu venture as part of their semester-long project. Students in such courses are not the self-selected highly-motivated students as in the core teams. These students are a cross-section of students who are now engaged in an entrepreneurial venture in a rigorous fashion.
6. **Course commissioned assignment:** A significant aspect of a venture is commissioned to a project-based course. For example, the business plan for the Mashavu venture was developed by a five-member team in the BA 301 HFinance honors class as a commissioned assignment. At least one member from the team attends the seminar class to ensure that the business plan is appropriate for the context and stay current with developments from other teams working on the same venture. This differs from the previous category because the entire class is not working on aspects of the venture and the course content has not been modified to meet the needs of the context.
7. **Independent Study:** A few students participate in various aspects of the ventures by signing up for independent study credits. They need to sign up for, or informally attend, the EDSGN 453 seminar class as well. Typically these are students at other campuses or professional degree



programs (e.g. MBA students) with tight stipulations on what will, and will not, count towards graduation. These students then coordinate with the core team and work on projects that don't need tight integration with the core team.

8. **Volunteers:** Volunteers are welcome to participate but they are not allowed to engage in field-work or lead a significant aspect of any venture. They can support the core venture teams on specific needs.

EDUCATIONAL ASSESSMENT METHODOLOGY

In order to examine the effectiveness and impact of the eplum model, a mixed methods approach was utilized, using both qualitative and quantitative methods of data collection and analysis. The data collection strategies included an online survey, student focus groups, and examination of students' responses to a course blog. These three sources of evaluation data provided evidence of the impact of HESE on both student perceptions as well as learning.

Survey

A survey was developed by the researchers involved in this study. The researchers developed a definition of the three constructs of interest: 1) Global awareness and engagement, 2) Multidisciplinary teamwork, and 3) Social entrepreneurship. The questions were written by the research team in a series of intensive meetings intended to identify the core components of each construct and to develop items to measure each construct. Interviews of fifteen faculty members and administrators across Penn State about their perceptions of these three constructs informed the development of the surveys. In addition to the three constructs, each item was written along dimensions of beliefs, attitudes, knowledge, and self-efficacy. The items measuring attitudes, beliefs, and behaviors, (here-tofore called the ABB Scale) were written as 5-point Likert items on a scale from Strongly Disagree to Strongly Agree. The self-efficacy scales used a 0 to 10 scale as suggested by Bandura [36].

Penn State students enrolled in five different classes participated in the evaluation during the Spring 2011 semester. Students were asked to complete the survey online at the end of the semester. A total of 120 students completed the survey. A total of 44 female students and 76 male students completed the survey. The majority of the students (74%) were from engineering disciplines. The classes selected to participate in the study were involved in HESE at a variety of levels, as described earlier.

Reliability and validity evidence of scale: Because of the different scales used in the ABB and self-efficacy scales, analyses for each were conducted separately. Reliability analyses using Cronbach's alpha were conducted on each scale. For the ABB scale, the alpha was calculated to be 0.79, which suggests good reliability. The reliability was slightly higher on the self-efficacy items at 0.86. Based



on the results of a classical item analysis, three items were removed from subsequent analyses due to negative item-total correlations and increased alpha if item removed. Two of these items were from the ABB scale section. The remaining item was a self-efficacy item. The revised ABB survey consisted of the following sub-scales: global awareness (11 items), multidisciplinary teamwork (10 items), and social entrepreneurship (11 items). The self-efficacy scale contained 7 items measuring global engagement, 6 items measuring multidisciplinary teamwork, and 4 items measuring social entrepreneurship related outcomes.

In order to gather validity evidence relating to the internal structure of the scale, an exploratory factor analysis was conducted on the survey data, using principal axis factoring with direct oblimin rotation. For the ABB scale, although there were ten factors with eigenvalues greater than one, the scree plot suggested three factors with eigenvalues of 6.134, 2.523, and 2.156. Combined, these three factors explained approximately 34% of the variance in responses. Analysis of the rotated pattern matrix suggested that these factors weakly map to the theoretical structure. Approximately five of the eleven items measuring global awareness loaded highest on the first factors; five of the items measuring teamwork loaded highest on the second factor. The third factor was less clearly defined with few items loading highly across all three subscales. The items on the social entrepreneurship subscale loaded in a balanced manner on both the first and second factor, suggesting similarities between students' perceptions of social entrepreneurship and their perceptions of multidisciplinary teamwork and global issues.

A second factor analysis was conducted on the self-efficacy items, using the same procedure. Five factors emerged with eigenvalues greater than one. However, examination of the rotated matrix suggested a moderate map to the theoretical structure using three factors, which explained approximately 53% of the variance in scores. Five of the six teamwork items loaded most strongly on the dominant first factor. On the second factor, five of the seven global items loaded highest. The social entrepreneurship items mapped to several different factors. Although the factor structures do not have a strong mapping to the theoretical structure, there is some evidence that a weak to moderate mapping is present. Therefore, we feel confident using the scales in the assessment of the HESE program in conjunction with other forms of data collection.

Data analysis

The primary research question for this assessment concerned how students' level of engagement with HESE impacted skills and knowledge relating to the three subscales on the ABB scale [global awareness and engagement, multidisciplinary teamwork, and social entrepreneurship] and the self-efficacy scale. In order to examine this question, a multivariate analysis of variance (MANOVA) was conducted using level of engagement as the independent variable and the three subscales on the



Level of Engagement	Description	Sample size
Highest	Enrolled in a course associated with the “core teams” of HESE ventures	32
Peripheral Classes	Enrolled in peripheral classes but not in a core team.	44
Control Group	Enrolled in an introductory design course without affiliation with HESE	40

Table 3. Levels of Engagement and Sample Size.

ABB scale as dependent variables. A separate ANOVA was conducted using self-efficacy as the dependent variable.

Students were categorized into three levels of engagement. Students identified as “High” were enrolled in EDSGN452 and 453, which indicated they were on the core teams. Students identified as “Peripheral” were enrolled in BIOE 401, ENGL 202C or other classes and were not members of a core team. Students identified as “Control” were enrolled in an introductory design class that did not have any affiliation with the program. Table 3 describes the levels of engagement and the sample sizes for each.

RESULTS

For the first assessment question, a MANOVA determined a significant main effect for level of engagement on the three subscale scores [Pillai’s Trace, $F(6,198) = 6.514, p < 0.000$]. Level of engagement had significant effects on the results of the global subscale ($p < 0.000$), the multidisciplinary teamwork scale ($p = 0.001$), and the social entrepreneurship scale ($p < 0.000$). Figure 3 displays

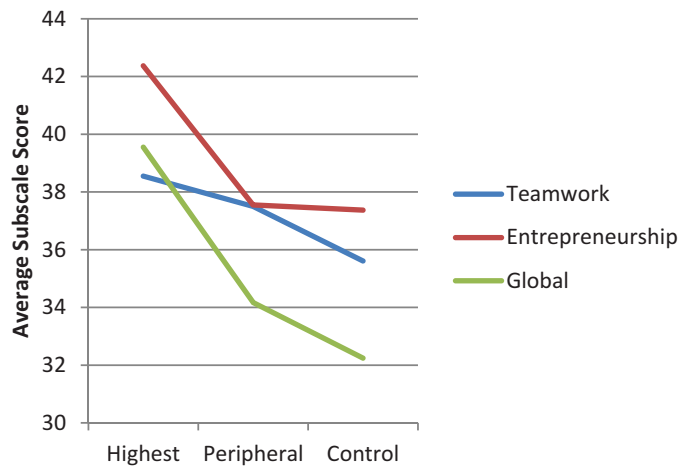
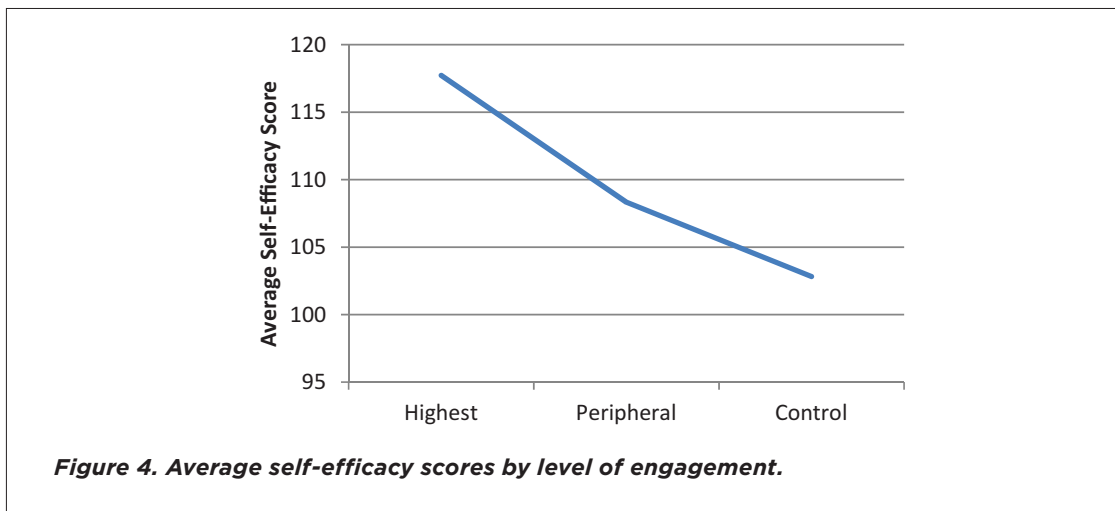


Figure 3. Average subscale scores by level of engagement.



the means for each subscale by level of engagement. The students enrolled in the highest level of engagement had significantly higher scores for all three subscales; scores were not significantly different between the peripheral and control classes. Using an ANOVA, level of engagement was found to have a significant impact on students' self-efficacy scores ($F(2,109) = 6.31, p = 0.003$). Students enrolled in the highest level of engagement had higher self-efficacy than those in the control group. Means of students in the peripheral group were not significantly different than either the highest level of engagement or the control group.

However, there are some trends corresponding to the program model. Students enrolled in the peripheral classes have higher subscale means as compared to the control group, particularly for global awareness and multidisciplinary teamwork. The rationale for the higher scores on these two sub-scales is that the students work in multidisciplinary teams on sub-projects in the specific global context. However, they typically do not get an opportunity to understand the systemic challenges and how the solution impacts the status quo, and make entrepreneurial decisions for the road ahead, the way the core teams do. While the differences are not statistically significant, the trends do suggest that students involved in HESE ventures in a more peripheral manner may still experience some of the benefits. The trend supports the theory and could be further substantiated with larger sample sizes.

Focus groups

The use of focus groups to collect qualitative data provided a rich context that complemented the quantitative data from the survey. Three separate focus groups were held with students who were working on one of three ventures championed by HESE. Each focus group consisted of 7-10 students who were from a variety of majors including both engineering and non-engineering fields. Students ranged from being freshmen to graduate students and participated in the ventures at



various levels of engagement. Both men and women participated in the focus groups. The focus groups were conducted by members of the College of Engineering's teaching and learning center. A semi-structured protocol was used to guide the focus group proceedings. The focus group protocol contained specific questions related to the three constructs. The facilitator of the focus groups identified these key comments from students' responses to the questions. The idea behind the focus group method is that group processes can help people to explore and clarify their views in ways that would be less easily accessible in a one to one interview. Group discussion is particularly appropriate when the interviewer has a series of open-ended questions and wishes to encourage research participants to explore the issues of importance to them, in their own vocabulary, generating their own questions and pursuing their own priorities [37]. All participants were encouraged to speak to avoid emphasis on one dominant voice. Students were encouraged to present their opinions, even if they disagreed with other students. Participation in the focus groups was voluntary. All focus groups were recorded and later transcribed.

The transcriptions were coded to determine students' perceptions of 1) the impact of the HESE projects on global awareness and engagement, 2) the impact on multidisciplinary teamwork skills, and 3) impact on knowledge and skills relating to social entrepreneurship and the need to help people around the world. Students shared that the HESE experiences allowed them to look at the needs and dependencies of a global society. Overall, the students believed that participation in HESE was an important learning experience.

Global Awareness

Regarding the construct of global awareness, the consensus was that students felt enlightened by their experience in HESE. Students commented on learning the importance of not only providing tools to improve life in Kenya, but also the need to understand the cultural values of the people who will use the tools. They also expressed that Kenyans valued trust over profits, which had been contradictory to their experience in their American culture. When asked, "What do you think it means to be globally aware?," students focused on understanding cultural norms. A business major shared that in the business program, "We have been taught globalization in just about every class. This [program] is adding a different layer. It is different in this class because it's hands-on working for a company that is in Kenya. In this class you have to know about the culture." Another student learned about the value of trust: "I learned about the culture in Kenya and how [the Kenyan people] value trust. Their professional network and social network is one and the same. Whereas here in America, it is all profit-driven. In Kenya, they would rather forego profit to work with someone they trust." One of the goals of the seminar course is to explicitly teach students to recognize and appreciate the differences in other cultures. The students appreciated its importance, but acknowledged



that the burden of responsibility was ultimately on them to identify the relevant norms of the local cultures and ensure that their designs and strategies were in harmony with the cultural mores. This is inline with the core HESE philosophy that the students are ultimately responsible for championing the ventures and need to do whatever it takes (within reason) to meet the venture goals.

Everyday forms of communication may tell us as much, if not more, about what people know or experience. In this sense, focus groups reach the parts that other methods cannot reach, revealing dimensions of understanding that often remain untapped by more conventional data collection techniques [37]. Students were asked, “How has participation impacted your sensitivity to cultural and individual differences?” They stated that they became aware of subtle cultural differences such as how to approach the Kenyan clients and how to appropriately place certain medical devices (i.e. under or over clothing), a factor that is often taken for granted in their own cultural experiences. One student commented, “We have to modify the underarm thermometer because it is too invasive. Women in Kenya don’t feel comfortable with this procedure.” Another student contributed that the “stethoscope may also be invasive. It is fine if women are checking [other] women in Kenya, but that can be an issue.” The students were in agreement that they were able to learn to recognize these issues because this was addressed and discussed across the various levels of engagement. There were a few students who said that certain disciplines do not require global awareness. For example, an agricultural engineering student said that skills related to internationalization will not help his future career.

Multidisciplinary Teamwork

When discussing multidisciplinary teamwork, students listed their top concerns as communication, delegation of tasks and positive interdependence. Positive interdependence is linking students together so one cannot succeed unless all group members succeed. Group members have to know that they sink or swim together [38]. When the students were asked, “What teamwork skills were required when working on this project?” one student volunteered “Communication! Delegation of tasks. It is difficult to keep everyone on task, especially [when] everybody is working on different roles.” Interestingly another student recognized the diversity of team members as it relates to individual responsibility: “The group is not too big but it is diverse in the sense that everybody has his own responsibility. So you can’t really check where everybody is at because you don’t have skills in that area.” As an example of positive interdependence, another student learned what it was like to depend upon the expertise of others and trust their expertise: “Be open-minded because you are working with a lot of different people who understand things better than you do.” As an example, a student who was working on a team with people who had strong technology skills felt this was an area where he or she was less confident in. This student commented, “You have to trust them... that



they know what they are doing. In the same way they had to trust that I knew what I was doing on the business side of things.”

In comparing working on a team for this project as opposed to their other academic teamwork experiences, students recognized this to be very different. Their comments focused on perceptions of teamwork in other courses, the different skill sets needed to have a successful team and the importance of collaboration across disciplines. One student said, “Definitely different [from other team experiences]. This one is really multidisciplinary. I think it is really great because people have different knowledge and skills. For example, business people develop business plans that I have no idea about. Some people have better personal skills like presentation skills.” On the necessity of diverse skills, another student commented, “My other teams are [made up of] people [who] have different sets of skills and you divide parts. If you don’t know how to do it, I can do it. But in this project, if you don’t know how to do it, I don’t know either and we all fail as a team. So you tend to trust your teammates more.” A student felt that participation in the program increased his self-efficacy and led to stronger feelings of identification with his major field of study. As he stated, “It makes you more comfortable about your major. You might think that you don’t know a lot about your major, but after you finish a project and present it and see how people rely on you for your knowledge. It is very comforting.”

Social Entrepreneurship

To determine how participation may have had an impact on students’ entrepreneurial motivations and future career goals, the researchers posed questions that focused on 1) identifying, 2) understanding and 3) acting upon world problems. When asked the biggest challenges facing the world, students referred to the millennium development goals related to health care, water, maternal health, and energy. A student who participated in Teach for America expressed that education inequality in the world is a big challenge. Students recognized systemic problems like unequal distribution of wealth, poverty, disease, and lack of governmental stability. For example, a student talked about alternate (non-technology) approaches to addressing global problems: “there needs to be a change in the way policy occurs, perhaps through world government.”

Focus group responses indicated that students understood the complexities of the problems and the inherent challenges in effecting social change. Students were asked, “How has participation in the project impacted your interest or likelihood in identifying, understanding, and acting on the problems that affect people around the world?” One student summarized her thoughts, “Providing these [less developed] areas with technologies is a good idea, but I think it is more or less a temporary solution. I can see them using it, I can see it being sustainable, but at the same time, I don’t like seeing them [the developing countries] relying on us [referring to more wealthy countries]. I



know that our goal is to provide them with something that they can be entrepreneurs and they can scale-up so they don't have to rely on us. But at the same time, it just seems like there is no one solution to all these problems. We need to do something more. If you really want to solve a problem, you need to look at the root causes.”

Students expressed how these challenges should be addressed from a systems perspective and cited green energy technologies as one such approach. An Information Sciences and Technology student commented that the impact on his understanding is to be open and willing to compromise as he may start a company that is “all over the world.” Another theme that emerged was the importance of an optimistic attitude and “the power of one person” philosophy. Students expressed their confidence in making a difference by themselves to address challenges in a sustainable fashion. Students talked about “teach people how to do things themselves.” When asked to describe the impact of the course on themselves, the group agreed that they were “inspired to get more involved globally and work towards a goal: engineers can learn from looking at women’s issues globally”; and a student said “I can apply these skills that I learned to work, travel, and teach...and not be stuck in a cubicle.”

Students' blog responses

In the EDSGN 453 course, students were required to write blog posts throughout the course. One of these blog posts was used for pre- and post-course assessment of the students understanding of issues related to entrepreneurship. The question asked of students during the first and last week of class was the following:

The World Health Organization estimates that over one billion people who need eyeglasses do not have access to them. The vast majority of these people live in developing countries like Kenya where there is barely one optometrist per one million people. Given the high poverty levels, access to eyeglasses is almost non-existent. Lack of proper eyeglasses severely impacts people and their livelihoods by decreasing their productivity at work, limiting or eliminating new opportunities, affecting their quality of life, deteriorating their general health and possibly leading to (preventable) blindness. What solution do you propose to address this problem?

Our hypothesis was that students who have not yet taken the course would provide responses that are less entrepreneurial in nature and relied more on solutions geared towards educating the citizens or obtaining donations from outside organizations. The blog responses were placed into a database with identifiers removed. A group of four researchers including the course instructor and three members of the teaching and learning center rated each blog response. Responses from



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the pre- and the post-assessment were combined so that the raters were unaware which responses came at the start or end of the course. After examining a sample of blog responses, a coding scheme was developed. Each blog response was rated on the following structure: High Entrepreneurial, Low Entrepreneurial, Donation-Based, Education-Based, or No Solution. Sample responses and definitions corresponding to these codes appear in Table 4. As a group, the four researchers read and discussed each student response and came to a consensus on which code best represented the students' response. In some cases, students' responses received multiple codes.

The frequency of coding for the blogs is available in Table 5. The number of responses coded as high entrepreneurial increased from 7 to 17, while the number of low entrepreneurial solutions was fairly consistent. The number of donation-based solutions decreased from 17 to 9. A chi-square test of independence was conducted (excluding frequencies from the no solution code due to small *n* in these cells). The result showed a significant difference between the distribution

Code	Definition	Example Student Response
High Entrepreneurial	Comprehensive solution that is economically sustainable and scalable. All aspects of the solution are elegantly explained.	“The solution of this problem depends on sustainability, which is why reliance on donations is not the answer. I would first focus on designing a low-cost pair of glasses that can be adjusted by the users themselves. The original mass production of the glasses would have to be funded by some outside source, but if enough glasses are bought then eventually the system could pay for itself. Entrepreneurs would be in charge of glasses distribution. If we are trying to alleviate eye problems on a large scale there needs to be a McDonalds-esque idea to the process. The glasses need to be able to be available everywhere across the world and the distribution/repair processes need to be standardized so that the effects are not short-lived.”
Low Entrepreneurial	Solution is entrepreneurial and has elements of economic sustainability. However, all aspects of the solution are not explained.	“I imagine a standard set of a scale of glasses could be developed, from higher vision ability down to lower vision ability. Then people could try on the range of corrective lenses until finding one that helps them... These glasses could be sold as kits, to start up small eye glass businesses.”
Donation-Based	Solution primarily focuses on relying on outside organizations or units to donate money or supplies in order to solve the problem.	“I would first suggest a grassroots effort in the United States to have old unwanted eye wear donated so they can be repaired or salvaged.”
Education-Based	Solution primarily focuses on educating or teaching the community in order to increase the number of individuals with the necessary skills to identify eye problems.	“Educational courses that highlight the importance of taking care of your eyes and keys to maintaining good eye health could greatly improve the eye care practices in Kenya and other developing nations.”
No Solution	Student failed to provide a solution, discussed other details, or response was unclear.	N/A

Table 4. Codes Used to Rate Students' Blog Responses.



	Pre-course responses	Post-course responses
High Entrepreneurial	7	19
Low Entrepreneurial	6	7
Donation-Based	17	9
Education-Based	6	4
No solution or unclear	2	3

Table 5. Frequency of coded responses for pre- and post- blogs.

of coding between the pre-course blog responses and the post-course blog responses ($\lambda = 18.88$, $df=3$, $p < 0.000$).

The results support that students' responses to the blog question changed after completing the course, with more students suggesting high-entrepreneurial solutions and fewer suggesting donation-based solutions. While there were still 9 responses that contained solutions relating to donations, it is important to note that 8 of these were coded as both donation-based and entrepreneurial (3 low-entrepreneurial and 4 high-entrepreneurial). The results of this analysis suggest that students are grasping the fundamental limitations of donation-based approaches to addressing development challenges. There is recognition of the importance of sound business models to ensure economic sustainability of social ventures. Students are proposing well-crafted entrepreneurial strategies that are practical, sustainable, and scalable.

Entrepreneurial Outcomes

For most students, their experience with HESE is transformational as it exposes them to situations, opportunities and career paths they had never imagined. Several students pursue Fulbright scholarships or service programs like Teach for America and Peace Corps to get additional field experience and earn Masters degrees before entering the workforce. A large number of students, and almost all of the highly-engaged students, pursue graduate school, medical school or law school. HESE students are pursuing an extremely wide range of non-traditional career paths, ranging from launching social ventures (e.g. low-cost feminine hygiene products) to repairing obstetric fistulas as qualified surgeons, to improving rural supply chains, to consulting with the World Food Program and Clinton Health Access Initiative. A common thread is that they consider themselves entrepreneurial global citizens and believe in the HESE quest to make the world a freer, fairer, friendlier, and more sustainable planet.

Over the past decade, HESE ventures, led primarily by undergraduate students, have collectively impacted the lives of a few million people across Kenya, Tanzania, Rwanda, India, U.S., Jamaica,



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Cameroon, and other countries. Some ventures have failed while others are on the slow but steady path towards sustainable existence and scaling up to become multi-million dollar enterprises. Basic infrastructure projects like community-scale anaerobic digesters, bridges, and computer learning centers are valuable in their own right but difficult to replicate and scale. One of the first entrepreneurial successes was an affordable windmill-based hybrid power system for rural Kenya developed and implemented by our team in 2007. The UN Industrial Development Office (UNIDO) collaborated and picked up on the technology and business model. They subsequently launched the “Lighting Up Kenya” initiative that built 12 energy kiosks around the country and is scaling up to build more such kiosks now. These kiosks have collectively impacted the lives of a few million Kenyans.

Using relatively simple yet innovative technology, Mashavu: Networked Health Solutions sends a customer’s medical history and vitals to a doctor, thus completing a consultation process, which would otherwise involve up to two days of travel and hospital wait, in less than twenty minutes. Our team partnered with former street-dwelling youth at the Children and Youth Empowerment Center (CYEC), UN Industrial Development Office, the Kenyan Ministry of Health, and other entities to develop and field-test low-cost ruggedized biomedical devices that can survive the harsh environment. After testing and iterating eight different business models, we finally arrived at a profitable model that provides full-time jobs to seven individuals, while meeting rural health challenges. These Mashavu Health Workers (MHWs) independently decide their operations, pricing, work area, and future strategy, embodying the empathy, equity, and ecosystems that form the bedrock of our engagement. Over the last four years, Mashavu has provided paid services to 40,000 customers and education on non-communicable diseases to over 120,000 individuals. The Mashavu team continues to work on the development of low-cost (\$0.10) ruggedized biomedical devices like inkjet-printed test strips to screen people for Urinary Tract Infections (UTIs) and diabetes.

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 too expensive (\$2,500) for small-scale farmers. Over the last six years, our team collaborated with diverse partners to design, prototype, and field-test affordable (\$600) greenhouses for small agro-enterprises and sustenance farmers. The farmers’ return on investment is 4-6 months. This technology has been formally licensed to for-profit companies in Kenya (Mavuuno Greenhouses Ltd.) and Cameroon (The Greenhouse Center). HESE teams worked with these startups to set up manufacturing facilities, train employees, forge partnerships with banks and microfinance institutions, establish supply chains, and develop marketing materials. In collaboration with a non-profit, World Hope International, and with support from a USAID Securing Water for Food (SWFF) Grant of \$500,000 over three years, similar greenhouse ventures have been launched in Sierra Leone and Mozambique. Operations are



underway to jumpstart similar enterprises in India, Egypt, Cambodia, Peru, Burkina Faso, Zambia and other countries. HESE Affordable Greenhouses can now be purchased in over 19 African countries. These independent enterprises, run by local entrepreneurs, deliver social impact without relying on donations and foreign aid. These are just a few examples of scalable ventures from the HESE program.

Research Outcomes

Participatory research helps understand the broader context and how the technology venture might benefit (or hurt) the communities involved. Through its organic and qualitative approach, such research can validate assumptions and gather relevant information to craft a venture's design, business, and implementation strategies. The findings of such research endeavors can lead to better designs and systemic solutions while the research process can build trust and ownership amongst the stakeholders and facilitate the implementation of the venture. While the findings are inherently focused on the specific context and not generalizable, the results can be highly-transferrable to other contexts. In essence, the goal of research (and publication) endeavors is not limited to proving a hypothesis or finding the answer to a specific research question. HESE students are expected to concurrently work on IRB-approved research studies that strengthen their ventures while inspiring and informing other innovators working on similar global development challenges [39].

As a public land-grant research university there is an emphasis on the integration of learning, research and entrepreneurial engagement so as to optimize venture accomplishments and provide rigorous educational experiences at the same time. An explicit goal of the program is to nurture Humanitarian Engineering and Social Entrepreneurship as a distinct and rigorous body of knowledge. Students and faculty in the HESE program conduct research and publish in many areas ranging from HESE education, systems thinking, social enterprise business models, failure modes of ventures in diverse sectors, access to capital and informal lending, indigenous knowledge systems, agricultural technologies, affordable biomedical devices, telemedicine systems, community health workers, science education, and cell phones and social networks. The research agenda is dynamic and evolves with the needs of the technology ventures undertaken and partners' interests. Making effective presentations and clearly articulating ideas is another essential skillset that students develop when they present at conferences and competitions <http://sites.psu.edu/pubhub/>. Since most of the HESE ventures need multiple years to mature, the research publications help pass the baton from one team to the next. Often, the teams exhaust what they can accomplish by themselves and the publications help connect to the larger community and find collaborators. Research and proposal writing skills are also extremely important for graduate school and for careers in social innovation and international development. Table 6 summarizes the research throughput of the HESE program from 2008 to 2015.



	Published	In Press	Under Review	In Prep	Total
Undergraduate Lead Author	63	5	9	19	96
Graduate Lead Author	22	0	8	9	39
Faculty Lead Author	21	0	1	1	23
Total	106	5	18	29	158
Conference Proceedings	54	0	4	8	66
Journal Articles	48	4	14	21	87
Book Chapters	4	1	0	0	5

*A list of HESE publications can be accessed through: <http://www.hese.psu.edu>

Table 6. Publications from the HESE program (2008 – 2015).

EVOLUTION FROM AN ACADEMIC PROGRAM TO AN ENTREPRENEURIAL ECOSYSTEM

Besides the academic frameworks described in this paper, the HESE program has developed several co-curricular programs and resources [36] to nourish student, professional and venture pipelines and increase the probability of success of the ventures. These activities transform the academic program into a vibrant entrepreneurial ecosystem. Several of these initiatives are works in progress and have been included in this article to illustrate the emergent frontiers and critical needs that need to be addressed to mainstream HESE at universities across the United States.

Student pipelines

HESE ventures benefit significantly from students that stay engaged in a particular venture over multiple years. To do so, it is important to recruit lower-division students into HESE classes. The eplum model, described earlier, is one approach to make lower-division students aware of global development challenges and opportunities offered by the HESE program. HESE hosts a competition called “Milking the Rhino: Innovative Solutions Showcase” that invites students to develop appropriate, innovative, and sustainable strategies to empower African indigenous communities to leverage natural resources for their self-determined development. The primary motivation for the creation of this showcase was to enhance student interest in global developmental challenges and recruit them into HESE courses where they can pursue their ideas and interests further.

HESE Fellows

As ventures in developing countries mature, it becomes critical to have core team members on the ground for longer periods of time to oversee operations. Towards that goal, the HESE Fellows program places 2-3 students (or recent graduates) in venture locations for a period of 4-6 months.



The fellows are chosen from the cohort of recent graduates that exhibited exemplary leadership in all aspects of the venture, from design, to business and implementation strategy development, and execution. This is a compelling learning and praxis opportunity for the Fellows as all their expenses are covered through venture-specific grants. After completing their Fellowships, students take on jobs in sustainable development, start graduate school, or take on additional fieldwork through Fulbright scholarships, Peace Corps or other similar programs. The Fellows' efficacy is further bolstered by formalized cross-college partnerships within the university and multi-sectoral partnerships with in-country organizations.

Professional Program Partnerships

HESE serves as one of the sites for the Global Health Scholars Program (GHSP) in the Hershey College of Medicine. GHSP's goal is to produce measurable and sustainable improvements in the health of residents in a specific, underserved community. This four-year program provides a structured and evaluated entrepreneurial engagement opportunity for students and faculty. Typically, 3-4 medicine students are accepted into the program every year after a competitive review process. This is a for-credit academic effort for the medicine students and is also tied to their Medical Student Research (MSR) requirements. Similarly, HESE works closely with the International Sustainable Development Projects Law Clinic in the School of Law that provides legal assistance to ventures. Law students in the clinic directly advise HESE teams on legal strategy, assist with deal negotiations, and draft necessary contracts and agreements.

In-country Partnerships

Venture partners in developing countries include diverse governmental entities, UN agencies, for-profit companies, non-profits, and community members. Appropriate entities are strategically engaged in relevant ventures at various phases across their lifecycle. For example, a local SACCO (Savings and Credit Cooperative) in Nyeri, Kenya helps conduct research in communities because it directly helps them with their own work. They have little interest in the ventures that emerge from the research endeavors in the longer term. On a completely different level, there are several tiny food shacks and private transport operators that provide trustworthy logistical services. Without these entities, the ventures would grind to a standstill immediately. In essence, a wider view of partnerships and relationships is essential to further ventures in resource-constrained environments. This is in perfect alignment with the philosophy of empathy, equity, and ecosystems that guides our engagement. Projects that emerge from, and are supported by, strong relationships are more likely to succeed than relationships that are formed to support specific projects.

**Design Resources**

The HESE program has developed several educational tools like an example-centric Global Biomedical Device Design Tool (www.globdd.com), one-page personas of stakeholders across food value chains, and customer journey-mapping tools. A recent thrust is on rigorous qualitative analysis of academic literature, online journals, and interviews with experts, to devise a taxonomy of potential failure modes for technology-based ventures in various sectors. Studies of failure modes during the engineering design, implementation, and maturity phases of agricultural technologies ventures and mHealth ventures have been completed with similar studies of other sectors underway. A related strategic effort is on identifying and articulating business models for various kinds of technology products and studying how diverse abiotic stressors influence these business models. These tools are intended to help HESE students as well as professionals in the design for extreme affordability and social impact space.

Career Resources

After pursuing immersive and engaged experiences like HESE, students are not as excited about taking up well-paying but monotonous jobs in large corporations. These students want to directly and tangibly see the human impact of their work rather than design a widget in a cubicle and becoming another cog in the wheel. While an increasing number of students are starting their social ventures, there are many others who just cannot, or do not want to, start a new entrepreneurial venture and life. With the intention of helping students make informed career decisions, the lead author interacted with hundreds of STEM innovators working on a wide range of societal challenges across diverse sectors, organization types, and roles within them. This effort resulted in a book, [Solving Problems that Matter \(and Getting Paid for It\)](#), that stitches together a mosaic of perspectives, experiences, and actionable insights to illuminate the smorgasbord of career pathways in social innovation and global sustainable development. The book includes 54 expert briefs penned by leaders from USAID, Peace Corps, MIT, Engineers Without Borders, AAAS, VentureWell and other organizations. In addition, 100 STEM innovators from the World Bank, UNICEF, White House, Gates Foundation, Google and dozens of social ventures, government agencies, nonprofits, academia and corporations share their enlightening and inspiring profiles, including their current roles and responsibilities, career trajectories and lessons learned along the way. The key message from this effort and the book is that engineers can pursue a wide range of impact-focused careers and earn a decent living while doing so.

Changing the Conversation

To make humanitarian engineering and social entrepreneurship commonly understood terms, approaches and fields of study, it is essential to educate the broader population. The common man's



perception of developing countries, and the African continent in particular, is largely based on what the popular media feeds them - violence, corruption, disease and starvation. While facts and figures about countries and cultures can be found with ease, deeper knowledge of systemic problems and “how things work” is relatively difficult to attain because research articles are not written for a broader audience. Stories provide a natural and meaningful learning context by transcending language, culture, and disciplines. The lead author fused his research findings with personal experiences, statistics, norms, emotions and illustrations to weave a series of fictional narratives called *The Kochia Chronicles: Systemic Challenges and Foundations of Social Innovation*. These stories take readers headlong into the lives and adventures of people in a quintessential Kenyan village as they usher in an era of design, innovation and entrepreneurship. They offer readers a glimpse of life, problems and innovations in developing communities against the backdrop of the rapidly evolving political, social, economic, technological, and global context. The stories educate people about a wide range of issues including the HIV/AIDS epidemic, the schooling system, traditional alcohols, gender issues, cell phones, innovation frameworks, community fundraising, and the inner workings of the orphanage business. Another endeavor aimed at educating people with limited attention spans is a daily cartoon series called Frame Changers. Frame Changers captures learning moments in the broad areas of HESE and Sustainable Development. These cartoons can be accessed on a blog site (<http://sites.psu.edu/khanjanmehta/framechangers/>) or on Facebook (<https://www.facebook.com/HESEFrameChangers>). An audience of about -20,000 followers validates people’s interest in sustainable development and the approach of leveraging humor to educate people about issues in sustainable development.

CONCLUSION

While several academic programs and student clubs work with communities, five things that set HESE apart are 1) extremely multi-disciplinary student and faculty teams, 2) emphasis on sustainable and scalable solutions, 3) a market-centric implementation approach, 4) integration of scholarly research and publication, and 5) focus on execution - getting the job done in the field. The emphasis on execution and sustainable impact continue to strengthen over time. While many faculty members and administrators view HESE, and similar entities, as a mechanism to develop soft skills (and meet ABET outcomes), that is not the *raison d’être* of the program. HESE exists, and strives, to address global development challenges while preparing a cadre of social innovators and international development professionals.

HESE’s vision of the role of academia considers the sustainability and scalability of ventures from the very beginning, and designs solutions that can be replicated tens or hundreds of times by



An Educational and Entrepreneurial Ecosystem to Actualize Technology-Based Social Ventures

independent (for-profit or non-profit) entities that are spun-off from the ecosystem. In this quest, the following questions have served as anchors and agents for instilling a sense of direction and humility: Does this project result in sustainable value for partnering communities? How will the value be measured? Does the project lead to self-determined development for the community? What are the results of the venture in the long-term? Can we scale-up to a multi-million dollar enterprise? These tough questions on the sustainability of projects in the larger context of globalization, professional ethics, and cultural balances have helped craft the program's academic offerings. Our experiences have taught us that such programs and emergent ventures can significantly benefit from a multi-faceted convergence of 1) concepts, disciplines, and epistemologies; 2) cultures and countries; 3) teaching, research, and engagement; and 4) multi-sectoral partners that share a common vision and purpose.

Engaging students in potentially high-impact social ventures can be extremely challenging and rewarding at the same time. Faculty members need to realize that the development of a program of this nature is a social venture by itself. An organic coalition-building process that is in harmony with the unique culture of the university needs to be employed. Faculty members need to gradually develop trusted partnerships with other faculty members, departments and centers in every college of the university. The idea is to identify champions in various pockets, work together to build confidence, and engage in larger collaborative entrepreneurial projects over time. Across this journey, a singular, almost obsessive and arguably delusional, focus on real-world social impact can preclude the endeavor from sliding back to a conventional learning-centered program after the initial excitement and funding fades away. In our experience, it requires several years of dedicated and persistent effort for the academic and entrepreneurial ecosystem to mature and successful ventures to start emerging.

The HESE program has carefully documented and published the pedagogies, mechanics, and methodologies for all courses and most ventures. While the successes have been chronicled, the failures and lessons learned have also been published. All the course materials, including PowerPoint slides and video clips, are available on public websites. These resources can help faculty from other universities jump-start their own academic programs. A critical mass of formal academic programs can help in altering the perception of such efforts from a "save the world mission with students going to poor countries to save people", to a rigorous, multidisciplinary, integrative discipline that inspires students and faculty to work shoulder-to-shoulder with communities to develop and launch social enterprises that deliver impact. As the developing world looks at "us" to solve their problems, can we learn from "them" to address our own challenges? In this interconnected world, there is no "us" and "them". We share wicked problems, dwindling resources and elusive quests for sustainable solutions. In this quest, engaged impactful scholarship can be transformative for the students, faculty, communities, industry, and most importantly, the engineering profession and the ivory tower itself.



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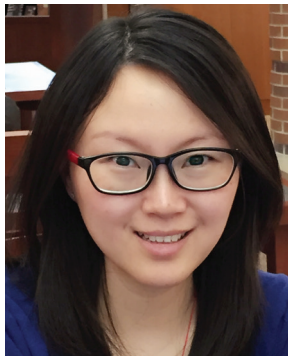
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