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## Guest Editorial: Entrepreneurship and Innovation in Engineering Education

PHIL WEILERSTEIN  
VentureWell  
Hadley, MA

AND

TOM BYERS  
Stanford University  
Palo Alto, CA

### BACKGROUND AND CONTEXT

This special issue of **Advances in Engineering Education** offers a selected group of papers that address key issues and questions in the development of Innovation and Entrepreneurship education for engineering students. The eight papers here present a useful and applied perspective on program construction, evaluation, impact and perspectives on how a focus on innovation and entrepreneurial learning can influence engagement and expand student participation. We solicited papers on the topic from the engineering education community and received 31 abstracts, 17 authors were invited to submit full papers for review ultimately yielding the eight papers selected for publication here. *Advances in Engineering Education's* online format provides a rich forum for the documentation of effective examples of practice and research, supported by access to multimedia. We hope that this issue will prove useful to those already engaged in this field as well as those who are seeking effective models to develop and pursue.

In this introductory essay we provide an overview of the growth of this dimension of engineering education, the development of the communities and organizations that have emerged to support it, and identify issues that the field faces as innovation and entrepreneurship become more ubiquitous in engineering education.

### THE INNOVATION AND ENTREPRENEURSHIP IMPERATIVE FOR ENGINEERING EDUCATION

In recent decades focus has increased dramatically on technological innovation and entrepreneurship as fundamental drivers of American prosperity and global economic leadership. The pace of



technological change has also accelerated greatly, resulting in the disruption of entire industries and the emergence of new ones. Engineering and science have been fundamental to these two trends, and technology entrepreneurs—from Steve Jobs and Bill Gates to Elon Musk and Mark Zuckerberg—are celebrated as cultural heroes.

The challenge now is to change engineering education to match the changes in the world at large. The innovation economy requires a new approach to preparing engineers, one that builds on and reinforces deep technical knowledge and analytical techniques while also equipping engineering graduates with the skills to be creative, empathetic, adaptable and to have the ability to recognize and act on opportunities. It is no longer sufficient to be technically qualified; to succeed, engineers must be prepared to understand the business context of decisions and contribute to, if not lead, the success of the organizations they join. Key skills now include effectively working on interdisciplinary teams, communicating ideas, thinking critically, understanding business basics, and being comfortable with solving open-ended problems.

Learning entrepreneurship in the context of an engineering education provides a means of learning these skills in an applied way. An entrepreneur in widely accepted definitions is “...someone who perceives an opportunity and creates an organization to pursue it” (Bygrave, 1991) or “...searches for change, responds to it, and exploits it as an opportunity.” (Drucker, 1985) Entrepreneurship education can be designed to prepare learners for a variety of settings and entrepreneurial roles. Many students are also drawn to entrepreneurship as a toolset for creating social impact, often in the context of low resource settings in the developing world. Although most media attention goes to entrepreneurs creating high growth startups, most engineering students are much more likely to join an existing company where their entrepreneurial skills support the agility and responsiveness of their organization.

Engineering education needs to provide students with the opportunities to learn and practice these skills. Engineering students can learn how to become innovators and entrepreneurs by learning the process through which an idea or invention is connected to useful application and a means of creating access to it (innovation) in a scalable way (entrepreneurship). Importantly, to do so they need to master the critical social skills of communicating ideas and developing networks. Learning to be an effective innovator and entrepreneur is not only about knowledge, it’s also about process, a process best learned in an experiential way.

In developing a program educators must make choices about what the goals are and what essential skills are needed by the majority of students, as well as how to support those students whose ambitions include leading a startup. Entrepreneurship education may also focus on creating an opportunity-oriented mindset combined with an understanding of basic business concepts, preparing them for a workplace in which they are expected to contribute to business decisions and create technical solutions that contribute to the bottom line.



Many universities and colleges do want their students to engage in technical innovation leading to startup activity, as do many students. Programming to support startups requires additional resources including mentors, networks and resources such as proof of concept funding, advising and pathways that lead the most promising teams to additional funding. Much of this activity is best suited to co-curricular or extracurricular programming that enables longer term engagement, and a more fluid set of constructs such as competitions and incubators that encourage the most promising ideas to garner support allowing the less promising ones to come to a graceful end.

Over the last twenty years, there has been a proliferation of entrepreneurship offerings for engineering students nationwide. Most institutions now provide engineering students some access through courses, with many offering certification programs such as minors and certificates along with co-curricular offerings such as competitions and student-oriented incubators. Unsurprisingly, these offerings tend to be popular with students and in high demand.

But despite this significant progress, many challenges remain. These programs typically reach a modest proportion of the engineering student population, are typically not well integrated with the core curriculum and often require students to stretch themselves to participate. Much remains to be done if we are to fully prepare the majority of engineering students for a working world that expects them to be innovative and entrepreneurial.

### **CREATING COMMUNITIES TO SUPPORT THE DEVELOPMENT OF THE FIELD**

The embrace of innovation and entrepreneurship (I&E) by engineering education has been a slow process. An applied discipline, engineering curricula have traditionally focused on technical and analytical skills, leaving graduates to learn the context in which they will apply those skills after graduation. The curriculum is crowded and there exists serious resistance to change due to the ever-expanding technical knowledge base and primacy of technical mastery over contextual application. The landscape of business has, however, shifted dramatically, as mentioned above. Employers of engineering graduates now want students who demonstrate an ability to understand and translate customer needs to technical solutions, who can work effectively in cross-disciplinary teams, and who can quickly adapt and contribute to both the technical and business success of the organizations they join.

Educators who focus on I&E are faced with the difficult task of inserting content in a way that connects knowledge with application and fits within a finite number of credit hours. To meet this challenge and enable the necessary change, several communities of early adopters have created the foundational approaches to broad incorporation of I&E. Over a period of almost two decades



there has been a steady but gradual change enabled by educational organizations and communities open to creating and adapting existing approaches to learning entrepreneurial skills to the engineering curriculum. Philanthropies and non-profits have played a role in this, catalyzing and sustaining communities of faculty practitioners with increasing experience and the capability to support the spread of these practices. We provide a short list here.

#### **VentureWell (formerly National Collegiate Inventors and Innovators Alliance)**

One of the first initiatives in this area was the National Collegiate Inventors and Innovators Alliance, renamed [VentureWell](#) in 2014. VentureWell, formed in partnership with The Lemelson Foundation in 1995, supports the creation of experiential learning opportunities in invention, innovation and entrepreneurship. Programs and activities are structured to disseminate and expand the adoption of this experiential approach in STEM and other disciplines in US higher education.

At the start, entrepreneurship programming outside of the business school was uncommon, and structures to legitimize and validate this activity were developed to engage institutional leadership and ensure support for the program offerings. To develop a community of practice, the VentureWell annual conference, Open, was created to provide opportunities for faculty development and dissemination of practice through academic papers, workshops and networking opportunities (Shartrand et al., 2012). In the ensuing two decades the VentureWell faculty community has developed over 600 pioneering courses and programs that engage tens of thousands of students annually in early stage exploration of science and technology ideas and inventions and their potential for development into products and services. The programs that faculty have created are diverse, ranging from elective courses in technology commercialization for graduate students to campus-wide certificate or minor programs for undergraduates. The common thread is experiential opportunities that focus on creating a scalable commercial opportunity in a team-based environment (an E-Team) in which both the design and construction of a prototype that validates the key technical premises and a scalable business model are created. Students learn the fundamentals of business and entrepreneurship, with the most promising eligible for training and support to launch products and businesses based on their inventions. Over the life of the Venturewell initiative students have formed over 400 companies that have raised over \$600 million in investment and provide products and services around the world.

#### **Roundtable on Entrepreneurship Education (REE)**

To build the community of engineering entrepreneurship practitioners, in 1998 the Stanford Technology Ventures Program (STVP) at Stanford University organized a gathering of faculty leaders of programs in entrepreneurship in engineering. During the course of the next 14 years, nearly 50 REE conferences on five continents were held, bringing together business, science, engineering



and design faculty interested in building leading-edge entrepreneurship programs and ecosystems at their institutions. This informal community served as a forum for emerging practices in program development and provided a sense of identity for a new structure, the engineering entrepreneurship program, as a valid and vital part of the engineering school.

### **The Entrepreneurship and Innovation Division of the American Society for Engineering Education (ASEE)**

In 1999, a small group of ASEE members with an interest in encouraging more focus on entrepreneurship and applied innovation came together at the ASEE annual meeting to discuss the creation of a new cross-disciplinary division. By 2000 the division had attracted several hundred members and its sessions became a focus for publication and presentation of peer-reviewed conference papers from across the engineering disciplines. Over the past decade and half, hundreds of papers have been presented, with a steady evolution from stand-alone curricular practice to the validation of tools for evaluation and approaches to the integration of entrepreneurial learning into the engineering core.

### **KEEN**

The [Kern Engineering Entrepreneurship Education \(KEEN\)](#) initiative was initiated in 2005 by the Kern Family Foundation (KFF) in collaboration with VentureWell. It began as a structured approach to creating educational opportunities in entrepreneurship for engineering students at private institutions, initially in the Midwestern US. Now a growing national initiative run by KFF staff, it has become a faculty-centered program engaging over 20 institutions in programming to equip engineering graduates with an entrepreneurial mindset that creates personal, economic, and societal value over the course of their career. The program has an explicit focus on developing business acumen and skills for customer engagement grounded in strong technical knowledge and societal values with a goal of engaging a majority of engineering students at participating institutions.

### **National Center for Engineering Pathways to Innovation (Epicenter)**

Funded by the National Science Foundation (NSF) in 2011, [Epicenter](#) is focused on expanding the infusion of I&E into undergraduate engineering education in the US. It does this by developing a better understanding of the needs of engineering students through research; engaging faculty and their institutions in creating widely available programming for undergraduate engineers to learn and practice I&E skills; and catalyzing student leaders to bring greater awareness and more opportunities for I&E to campuses.



Epicenter's scholarly research activities led by the Fostering Innovative Generations Studies team are designed to answer questions about the structure of engineering entrepreneurship education, how I&E affect engineering students' interests, and how students can learn entrepreneurship in technical environments.

The [Pathways to Innovation Program](#) is designed to help institutions transform the experience of their undergraduate engineering students and fully incorporate I&E into courses, co- and extra-curricular offerings and to modify policy and practice that enable broad access to I&E offerings. Participating schools assemble a team of faculty and academic leaders to assess their institution's current offerings, design a unique strategy for change, and lead their peers in a transformation process. The fifty universities participating in the program have developed hundreds of new programs and courses serving thousands of students on their campuses.

The [University Innovation Fellows](#) program trains student leaders to analyze their campus I&E landscapes and create offerings that help their peers develop an entrepreneurial mindset and creative confidence. The program has recruited 450 Fellows from over 150 institutions across the country.

#### **I-Corps™ and the National Innovation Network**

The [I-Corps™ program](#) was created by the NSF in 2011 in collaboration with VentureWell and a national network of over 45 research universities. Its primary focus is on helping to move NSF-funded academic research to market. Participating teams, including faculty PIs, take an accelerated version of Stanford University's [Lean LaunchPad](#) course, which engages participants in identifying opportunities by talking to potential customers, partners and competitors and navigating the challenges and uncertainties of creating successful innovations. Hundreds of engineering faculty have participated in the program with over 50% reporting that they will use their new knowledge in their teaching. While it is still early in the evolution of this program, its intensive nature and the scale at which it is offered will likely have an impact on the openness of engineering faculty to supporting entrepreneurial activity by their students as they are exposed to peers who have participated in I-Corps™ programs.

All of the national programs described here are designed to spread knowledge, encourage the development of local programs and resources, and support faculty as they embed entrepreneurship in the engineering curriculum. The growth in the number of courses and programs is impressive and will need to be sustained to achieve broad exposure for engineering students. Moving forward, it is critical to ensure that tools for evaluating and assessing what is being learned are developed and disseminated. As Purzer and her colleagues illustrate in their article in this issue, much work remains to develop a comprehensive and coherent set of tools and metrics.

A further area of concern is the need to develop approaches to entrepreneurship that are inclusive and improve diversity. The gender imbalance in the technology startup world that has attracted



attention recently is emblematic of a wider problem that requires thoughtful and proactive approaches to solve. We must ensure that the programs, networks and resources being developed to support engineering entrepreneurship are as engaging to women as they are to men and are relevant and inviting to students from all ethnic and racial groups.

### A BRIEF OVERVIEW OF THE PAPERS IN THE ISSUE

*Purzer, Fila and Nataraja* evaluated approaches to assessing engineering entrepreneurship education by evaluating the literature. They found a number of important gaps and a need for definition. They propose a taxonomy to guide the development of assessment tools for engineering entrepreneurship going forward.

*Duval-Couetil, Shartrand and Reed* described models for engineering entrepreneurship education in a study that provides a foundation for understanding the kinds of entrepreneurship education best suited to engineers. They determined that multidisciplinary programs can provide students with broader exposure to business concepts relevant to engineers; that participation in entrepreneurship-related experiential activities should be integrated into courses and programs directed at engineers; and importantly that at least two courses are necessary for engineering students to feel confident in performing entrepreneurial tasks.

*Besterfield-Sacre, Zappe, Shartrand and Hochstedt* characterize the content included in entrepreneurship courses for engineering students, how faculty teaching the courses believe that content knowledge and skills should be balanced and how that balance affects student learning of attitudes and values, as well as skills.

*Soundarajan, Camp, Lee, Ramnath and Weide* describe NEWPATH, an immersive program that engages computer science students in a linked sequence of experiential learning opportunities including entrepreneurial internships, immersive intensives and venture development opportunities. The importance of a community of peers and connections to real world resources emerged as key elements that contribute to success in learning and doing.

*Neumeyer and McKenna* used peer evaluation data to understand the real time impact of a design and innovation course involving team-based learning and real world interaction. They report that the experience improved skills related to new business development and enabled a clear-eyed perspective on their own interests and ambitions.

*Cobb, Hey, Agogino, Beckman and Kim* studied alumni perspective on a new product development course after entry into the working world and report that the class experience was deemed realistic and useful and can inform the future design of new product development education.



*Mehta, Zappe, Brannon and Zhao* explore the ways in which a social impact venture focus informs and drives learning and progressive development of skills over a long period by providing a compelling purpose that enables the participating learners to connect the technical knowledge and its application to the cultural context, user needs and the construction of partnerships to realize the larger goals.

*Dzombak, Mouakkad, and Mehta* explore the motivations of women participating in a technology-based social entrepreneurship program. They describe how the key elements of multi-disciplinary teamwork, ethical decision-making, systems thinking, and global engagement contribute to the development of an entrepreneurial mindset through practical real-world experience, an introduction of broader skill sets and exposure to diverse subjects. This experiential, real world framework contributes to greater engagement from women and a belief in their ability to make meaningful professional contributions.

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## AUTHORS



**Tom Byer** is the first holder of the Entrepreneurship Professorship endowed chair in the School of Engineering, and also a Bass University Fellow in Undergraduate Education at Stanford University. He has been a faculty director since the inception of the Stanford Technology Ventures Program (STVP), which serves as the entrepreneurship center for the engineering school. STVP includes the Mayfield Fellows work/study program for undergraduates and the Entrepreneurship Corner (ECorner) collection of thought leader videos. He is a principal investigator and the director of the Epicenter, which is funded by the National Science Foundation to stimulate entrepreneurship education at all USA engineering and science





colleges. He is the co-author of a textbook called *Technology Ventures: From Idea to Enterprise* that is published by McGraw-Hill.

Tom is a past recipient of the prestigious Gordon Prize by the National Academy of Engineering in the USA and Stanford University's Gores Award, which is its highest honor for excellence in teaching. He has been a member of advisory boards at Harvard Business School, UC Berkeley, World Economic Forum, Conservation International, and several private enterprises. He was executive vice president and general manager of Symantec Corporation during its formation, and started his business career at Accenture. Tom holds a BS in Industrial Engineering and Operations Research and an MBA from UC Berkeley. He also earned a PhD in Business Administration (Management Science) at UC Berkeley.



**Phil Weilerstein** has been the chief executive of [VentureWell](#) (formerly known as the National Collegiate Inventors and Innovators Alliance or NCIIA), a US-based NGO formed to stimulate and support the incorporation of innovation and entrepreneurship in higher education since 1996. He leads the Pathways to Innovation program, an NSF Engineering Education Center jointly run with Stanford University. Phil designs and oversees programs that encourage curricular innovation and student venture creation, provide resources for faculty and student entrepreneurs, and develop community through conferences and workshops for faculty and students with a focus on encouraging socially beneficial application of technological innovations and the improvement of entrepreneurship and innovation education in higher education. Phil's tenure with VentureWell is marked by his skill for network-building and expert leverage of resources. As an entrepreneur in a non-profit organization, he has grown VentureWell from a grassroots group of enthusiastic faculty to a nationally known and in-demand knowledge base and resource center. Mr. Weilerstein attended the University of Massachusetts where he was a co-founder of a biotechnology company developing naturally occurring pest control products. He is a Founder and Past Chair of the ASEE Entrepreneurship Division and recipient of the 2008 Price Foundation Innovative Entrepreneurship Educators Award and the 2014 Engineering Entrepreneurship Pioneers Award from ASEE.