Beyond "The Innovator's DNA": Systematic Development of Creative Intelligence in an Engineering Entrepreneurship Program

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Muir has been interviewed by Gerri Willis of CNN and by Bloomberg Radio, and has been published and quoted in numerous publications including Business Week and The Scotsman Guide, a prestigious magazine for the banking, mortgage, and investor industry. Douglas was the host of The Doug and Eric Show on ABC, "Exposing the Hidden Truths about the Three Credit Bureaus and the Banking and Finance System". He was featured in Kaihan Krippendorff's business tactics book, Hide a Dagger Behind a Smile, which described how Muir infiltrated the insurance industry and locked out his competition.

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Ms. Pyle is also the founder and President of Pyle & Associates, LLC, an Interim Executive Management firm providing management and business consulting services across diversified industries. Her extensive experience in business development, strategic planning, marketing, operations, and leadership have left a lasting impact on overall business performance from start-up to turn-around situations. Ms. Pyle is recognized for her unusual ability to quickly create clarity around key issues to ensure that strategic plans are developed, executed and monitored for success. This clarity of vision is informed by her highly diverse career, starting as an exploration/development petroleum geologist, including a brief stint in education when she lived in Venezuela, and to the present day when her clients have ranged from a heavy equipment manufacturer to a discount brokerage and a biotech firm.

Ms. Pyle holds a MBA degree from Averett University, a MEd. from the University of Houston, and a BA in Geology from Cedar Crest College. She has served on various boards including the Board of Directors for the Charlottesville Venture Group where she chaired the Business Plan Review and Annual Business Forum Committees. In addition, she has served on the Charlottesville Business Innovation Council and as a founding Director for the Business Growth Network. She also served on the board of the Division of Professional Affairs Advisory Council for the American Association of Petroleum Geologists.

Known for her candor and high ethical standards, positive energy and astute people skills, she has become a valued resource for business incubator programs throughout Virginia and her success as a business consultant is reflected in the successful outcomes of her clients.

Beyond "The Innovator's DNA:" Systematic Development of Creative Intelligence in an Engineering Entrepreneurship Program

In a seminal paper published in the *Harvard Business Review* in 2009 and titled “The Innovator’s DNA,” Dyer, Gregersen, and Christensen argue that there are "five discovery skills that distinguish the most innovative entrepreneurs from other executives." The specific skills they identified through their research were (1) associating, (2) questioning, (3) observing, (4) experimenting, and (5) networking. All of these, they argue, can be deliberately cultivated (as opposed to being innate). The broader category they use to describe the confluence of these skills is "creative intelligence, which enables discovery yet differs from other types of intelligence [because it] engage(s) both sides of the brain.” Associating, which they define as “the ability to successfully connect seemingly unrelated questions, problems, or ideas from different fields,” is the culminating skill. They liken associating to “a mental muscle that can grow stronger by using the other discovery skills. . . .The more diverse our experience and knowledge, the more connections the brain can make.” The article is only seven pages long and is more suggestive than prescriptive.

The book by the same title that they published in 2011 (*The Innovator’s DNA: Mastering the Five Skills of Disruptive Innovators)* is superficially similar but substantively different from the article. It expands in great detail on the skills but does not develop the metaphor underlying the book’s title. The authors neither mention the concept of creative intelligence nor propose an alternative characterization of the capacity that the five discovery skills are supposed to develop. They treat innovation as operations and processes punctuated by success stories of disruptions whose logic is apparent in hindsight but has little to no predictive power. This emphasis on processes and operations is pervasive in book-length popular treatments and scholarly discourse on innovation and entrepreneurship. In sum, it tends to reduce entrepreneurship education to what *can* be taught.

Of course, this is not the *intent* behind entrepreneurship education, but it is often the unintended consequence of good intentions gone astray. Entrepreneurship educators are understandably excited about the opportunities for financial success, personal fulfillment, and realization of the commercial potential of engineering innovation that entrepreneurship offers. Unfortunately, the enthusiasm for setting up *systems* that *produce* entrepreneurs can obscure the fact that disruption is by definition *un*systematic and unpredictable. The result is often what might be called an industrial production model of engineering entrepreneurship that reduces it to component skills.

In this paper, we argue that education for engineering entrepreneurship and innovation should include not only specific procedural information about customer discovery, business opportunity analysis, and business planning, but also a broader understanding of sociotechnical systems and the broader context in which engineering entrepreneurs operate. The discovery skills described in the original “Innovator’s DNA” article entail a broad range of knowledge and experiences consistent with the "broad education" specified by the ABET 2000 criteria. By implication, the skills portray “broad education” as a cornerstone not only of engineering education but also of education for entrepreneurship and innovation.

From a disciplinary perspective, this broader understanding is most comprehensively embraced by the humanities and social sciences generally and the specific field of Science, Technology, and Society (STS). In a crowded engineering curriculum with few electives, skills and processes could crowd out the diversity of expertise that is the heart of creative potential. Liberal education is the oldest and most proven system for balancing depth and breadth in the structured exploration of knowledge ecosystems that lack clear boundaries. STS is a modern, interdisciplinary realization of liberal education that responds to and is applicable to the context in which technological innovation takes place.

We are beginning to understand that STS and liberal education more generally are underexploited assets in engineering entrepreneurship education. As the material that follows acknowledges, we did not begin with a theory that an engineering entrepreneurship program housed in an STS department would have distinctive potential for developing creative intelligence. But we increasingly suspect that connecting entrepreneurship both organizationally and intellectually to liberal education may be a valuable corrective of the tendency toward an industrial production model of engineering entrepreneurship.

Context: Our Programs and Their Evolution

The material presented in this paper could be taken to imply that the problems outlined above were the ones we set out to solve when we created our Engineering Business and Technology Entrepreneurship programs in the School of Engineering and Applied Science (SEAS) at the University of Virginia. On the contrary, like many other innovative enterprises, our programs began with recognition of opportunity: recognition by relevant stakeholders (alumni, school leadership, and undergraduate engineering students) that an introduction to business concepts and language could give engineering graduates a competitive advantage. Our thinking has expanded and evolved over the years as one of us (a serial entrepreneur who has recently begun teaching technology entrepreneurship and engineering business) has realized the benefits of expanding, deepening, and diversifying the activities that precede the creation of a business plan.

These programs have been decisively but subtly shaped by the context in which they have developed, the Department of Engineering & Society, which is quite heterogeneous. It combines six distinct areas of expertise and activities in addition to entrepreneurship and business: (1) STS, (2) general engineering, (3) applied math, (4) experiential learning, (5) international programs, and (6) an engineering honors program. We have quite an eclectic mix of faculty in terms of formal training, professional work history, instructional styles, modes of interacting with students, and career paths. Across the department, we have unusually permeable boundaries between technical and non-technical areas and between curricular and extracurricular activities. As the subsequent description of programs will demonstrate, we also have quite permeable boundaries with the other departments in the School of Engineering and with respect to our institution as a whole.

Our initial offering was an Engineering Business Minor (EBM) that was established in 2004 as a school initiative for engineering students only. The EBM is a six-course (18 credit) program that consists of three required courses (COMM 2010, Introduction to Finance and Accounting; ECON 2010, Microeconomics; and STS 4810, New Product Development) complemented by three electives offered by various departments in SEAS, the undergraduate business school, and the economics department.

The minor is very popular. We typically get 200 applicants, but we accept only about 120 students so that we can match student demand with the number of seats available in the required courses. Students are selected for the minor based on their cumulative GPA and other factors, such as whether they have had an internship or other job that has helped them learn about careers that combine business and engineering. We currently have over 350 students enrolled in the minor. This is about 15% of the undergraduate population, and the EBM is larger than any engineering major. Engineering students, especially advanced undergraduates, spend most of their time in courses populated only by students from their particular major. In the EBM, students from different engineering majors interact, an optimal condition for the cross-disciplinary pollination that can lead to creative insight.

One key feature to making the program workable is that most of the required courses for the minor meet requirements for humanities and social science (HSS) and Science, Technology, and Society (STS) courses. All students, regardless of their major or minor, are required to take three required STS courses: STS 1500: Science, Technology, and Contemporary Issues (currently taught as “Great Inventions”), STS 4500: STS and Engineering Practice and STS 4600: The Engineer, Ethics, and Professional Responsibility. We encourage students to make connections between what they do in their required STS courses and what they do in the entrepreneurship and business courses and programs.

Some of the STS elective courses listed below were specifically developed for the business minor. Others were developed for other reasons but recognized as relevant for the business minor. The Science and Technology Policy courses were designed to support the Technology Policy Internship program that we have been running for over ten years. All of the 2500 courses fall under the category of Science and Technology in Global and Social Context. All students are required to take one course from this category as part of the STS requirements.

STS 2500: Engineers as Entrepreneurs
STS 2840: Entrepreneurship Financing
STS 2500: Service Science, Management, and Engineering
STS 2500: Business Ethics
STS 2740: Earth Systems Technology and Management
STS 2860: Intellectual Property, Engineering, and Society
STS 3020: Science and Technology Policy for Interns
STS 2620: Science and Technology Public Policy

Students may also select elective courses for the EBM from general engineering courses and courses taught in other engineering departments. Most of these explore the intersection between an engineering discipline and particular contexts of practice. Those courses are also listed in the appendix. We engage in an ongoing process of determining what new courses are being offered inside the engineering school that would be suitable for the engineering business and technology entrepreneurship students. This process allows us to discern interconnectivity among courses and departments, identify potential efficiencies, and take students into new social and intellectual settings.

Most of the HSS elective courses for the EBM reflect particular contexts where business skills are relevant (such as the arts or electronic commerce or international business). Others are concerned with the intersection between commerce and other areas such as law or ethics, or areas where social concerns (sustainability, for example) intersect with business. Yet others are concerned with particular areas of business activity, such as accounting or consulting, or with significant institutional interactions such as business, government, and society or information technology in finance. A few are collaborations between commerce or economics and other departments or programs such as sociology, history, or arts administration. A complete list of these elective courses is included in the appendix.

Our Technology Entrepreneurship Program is part of an institution-wide Entrepreneurship Program that manifests itself in different ways in different parts of the institution. The entrepreneurship program was established after the engineering business minor and puts more emphasis than the business minor does on activities that are outside of courses and classes. Its aims are similar to those of most engineering entrepreneurship programs: to promote a mindset that charges students and faculty to challenge the status quo, create, innovate, and drive change.

Specifically, it aims to (1) **prepare** students to play crucial roles in the new venture community—whether as founders, funders, policy makers, technologists, or executives—thereby positively impacting the world in which we live and creating value of all kinds; (2) **connect** entrepreneurship efforts across multiple disciplines and schools/colleges through a coordinated and collective curriculum; and (3) **provide** experience with the tools, techniques, and transformations involved in new venture development (e.g., ideation and innovation, team building, product-market fit, financial and social return, policy and legal dynamics), not only in start-up companies, but also in new ventures within or launched by established firms.

There are a few universities that seem to have taken a similarly holistic approach to growing an entrepreneurship program and community. Here we discuss two examples: Rice University's "Freestyle" entrepreneurship initiative and Cornell University's "Entrepreneurship Across Cornell" program.

Rice University's Freestyle program brings together students, faculty, administrators, and members of the Houston community and engages them in discussions and activities that explore the entrepreneurial mindset through multiple lenses, including those of the sciences, humanities, arts, and various professions. The Freestyle approach is broad and integrated and uses different methods of delivering knowledge and experiences, including traditional lectures, coursework, research experiences, and performances. Each year, the program explores multiple interdisciplinary themes that engage experts and practitioners not only across disciplines and professions, but also in the world beyond Rice University.

Cornell University's Entrepreneurship Across Cornell Program is a collaboration among 14 different divisions and schools. It is designed as a university-wide program to foster the entrepreneurial spirit in all students and faculty from each college, in every discipline, and at any stage of career. The goal is participants in the program to acquire entrepreneurial knowledge that can add significant value to any working environment – from the smallest concept to start-up to the largest business and from non-profits to government. The program also has a governing body composed of 90 Cornell alumni.

The structure of Cornell's program mimics the process of entrepreneurship from idea generation to de-risking to funding to scaling to launch. There is plenty of support in place to nurture the students and projects as they move from one stage to another – mentors, community knowledge, resources/deals, and online tools. Our entrepreneurship program seems to fall in between the approaches of Rice and Cornell. Perhaps more importantly, our situation allows us to view entrepreneurship and engineering business from a distinctive perspective and to recognize potential problems that are emerging (and from which we are certainly not immune).

Good Intentions Gone Astray? How Entrepreneurship Gets Reduced to Composite Skills

An article published in *The Journal of Engineering Entrepreneurship* in 2015 by Duval-Couetil, Kisenwether, Tranquillo, and Wheadon illustrates one path by which entrepreneurship gets reduced to composite skills. Titled "Exploring the Intersection of Entrepreneurship Education and ABET Accreditation Criteria," it maps possible outcomes of curricular initiatives in innovation and entrepreneurship to six of the 10 outcomes specified by Criterion 3 (e, d, f, g, h, and j). In theory, this would seem to be a positive finding that would provide justification for including innovation and entrepreneurship in the core curricula of engineering degree programs. But the results demonstrate how reductionist such an approach can be. For example, "I am comfortable explaining my project in various oral formats such as project review meetings, student forums, and research" could be part of but is not the full realization of professional and ethical responsibility (3f). The question, however, is not *whether* education for innovation and entrepreneurship can be justified in terms of ABET criteria. It is, rather, how the non-STEM components of engineering education can be used to maximum advantage in helping students develop the creative intelligence that lies at the heart of innovation.

An even more striking example of reductionism is exemplified in a paper that was presented at the 2014 Annual Conference of ASEE, "Deconstructing the *Innovator's DNA*" (Mathis, Fila, and Purzer). The authors present the results of a content analysis of innovation case studies that seeks to establish *which* of the discovery skills is used most often by experts as well as the *order* in which they are most often used. Their quantitative analysis does yield some suggestive results, such as "Expert innovators use observation, questioning, and experimenting more often than association or networking," and "Observation and questioning are skills that students may not completely understand . . . . [so] Engineering educators should look into developing a deeper practice with these skills." Instead of inquiring into *why* this might be the case, they offer suggestions such as "that educators look into spending more time on activities that use these skills. . . .[and] Faculty could have students practice Socratic questioning during team projects and presentations." While these conclusions and suggestions are reasonable, they are also generic and lack depth.

A Promising Alternative: Recognizing Opportunity in the Ebb and Flow of Everyday Life

The terminology and concepts associated with innovation and creativity are notably indistinct, overlapping, and numerous. Since Gardner proposed the concept of multiple intelligences in 1983, researchers working in several different fields have identified distinct forms of intelligence and established connections between those and (a) various forms of imagination and (b) a range of emotions. "Creative intelligence" is not a clearly defined concept, but it does suggest a capacity that can be cultivated and explored.

In "Creative Intelligence and Its Application to Entrepreneurial Opportunity and Ethics" (2012), Murray Hunter, who is affiliated with the Centre for Communication & Entrepreneurship at the University of Malaysia Perlis, offers a much more detailed and in-depth explanation of creative intelligence, which he describes as a "metaphoric concept" that is best understood in the context of "many fields and topics, including relatedness and influence of time and space on innovation, thinking, cognition, intelligence, and creativity" (p. 69). His basic definition of creative intelligence is this: "Creative intelligence is a term grouping together the cognitive and non-cognitive aspects of creative generation like intense interest, motivation and other social influences. . .[and also expands] the concept of creativity by placing importance on the contextual and environmental variables at hand and on thinking processes, applications, or style on the other" (p. 102).

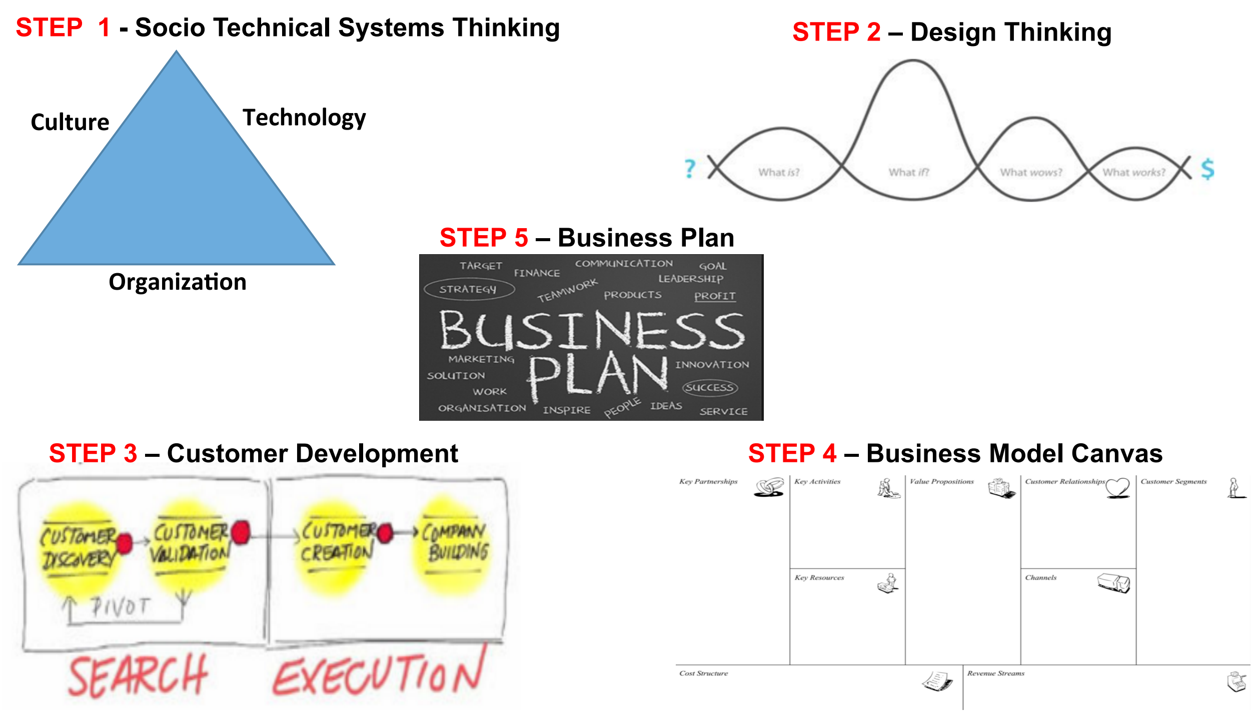
Hunter offers several metaphors that are helpful in understanding the nature of creativity and the way it operates. One of the most powerful of these metaphors likens the market system "to the *ebb and flow* of a tide. The market environment is a culmination of time, place, technology, society, government, suppliers, customers, and competitors. It's an emerging system where new entities, business models, inventions, and ideas spin off the *"ebb and flow"* of the possible. Entrepreneurial opportunities exist as rocks uncovered by the *"ebb and flow"* of the tide" (p. 75). Extending the metaphor, Hunter explains that "The *"ebb and flow"* of the tide embraces complexity. It appears very simple, but actually is the manifestation of complex interrelationships. . . .Tide is similar to the invisible effect that occurs within the environment, appearing simple but the forces behind it are extremely complex" (pp. 76-77).

The understanding emerging from these descriptions is that creativity is a phenomenon and set of complex and dynamic relationships that bears no relevance to any structured system like the one that emerges from *The Innovator's DNA* and other useful but ultimately limited process approaches to innovation. The interesting question to ask then, is what kind of "program" can provide students with a fluid understanding of the fundamental nature of the creative process and the capacity to operate in an original way within that process. Our answer: an intellectual model that integrates thought patterns (what might also be called "philosophies") with the processes that have proven so effective in the later stages of entrepreneurship.

If properly implemented, this model can create a series of "personal disturbances which bring chaos and then allow us let go of existing knowledge to replace it with new knowledge. This process involves synthesis in thinking rather than linear thinking and is a deeply emotional experience" (Hunter, quoting Robinson and Rose, p. 113) Hunter continues, "Creativity and original thinking are most likely to occur where the environment metaphorically collides, where paradoxes co-exist, where incongruities develop, where new technology is more efficient than older technology, and where better ways of doing things can be discovered" (p. 126). The un-programmatic programs described in this paper seek to create such an environment.

Next Steps: Developing an Intellectual Model for Integrating Creative Thinking and Problem Definition with Planning and Implementation Processes

The model we have arrived at broadens the back end of the entrepreneurial process by expanding, deepening, and diversifying the activities that precede the creation of a business plan. The model is depicted visually below.



The first two parts of the model, sociotechnical systems thinking and design thinking, both involve thought patterns and mental models. Step 1 entails mapping and analyzing the entrepreneurial space as a sociotechnical system that integrates technology, organizations, and culture. Though these three elements are intertwined in any given system, they can be distinguished from each other. Each suggests a set of questions. The questions in the *technical* domain are concerned with "stuff" (material things both human made and naturally occurring) and how the stuff works. The questions in the *organizational* domain are "who" questions, such as Who pays? Who cares? Who does it? Who makes the decisions or regulates the activity? Questions in the *cultural* domain are best understood as "why" questions. They are concerned with motivations and the expectations and values we use to justify decisions. (This conception of sociotechnical systems was developed by Arnold Pacey in *The Culture of Technology* (1983).

Design thinking is an approach to problem definition that has been widely embraced across sectors but that is particularly suited to creative problem definition in engineering. Jean Liedtka (2011, 2014) is arguably the leading scholar in the domain of design thinking, but the approach has been adapted in many different contexts. At its core, design thinking is an iterative process of asking fundamental questions, seeking answers, representing ideas visually as well as verbally, and recognizing the human element in a problem domain. Like sociotechnical systems thinking, design thinking seeks not just problem definition, but rather *creative problem re-definition*.

Steps 3, 4, and 5 (all processes) are concerned with discovering customers, getting customers to validate whether (or not) the solutions being proposed are appealing to them, creating customers, building a company, and modeling and evaluating alternative business opportunities. Creating a business plan is the culminating step of an extended exploratory, evidence-based process shows strong indications of delivering superior results.

Of course, no student could be reasonably expected to have the knowledge required to answer all the questions that would arise in a sociotechnical systems analysis or design thinking process. On the other hand, if students have (1) research and critical thinking skills, (2) analytical frameworks that guide the exploration of the entrepreneurial space, (3) a variety of strategies for organizing their thinking, and (4) first-hand experience applying the approaches of the HSS, we do not have to worry about covering everything they might need to know because they will be able to learn what they need as they go along. If we succeed in providing students with this foundation, we can truly say that we have equipped them for lifetime learning.

We suspect that anyone who has studied entrepreneurship and its history realizes the successful innovation occurs when capability meets the right circumstances. We are not claiming to have a system that can overcome the elements of timing and chance. We do believe, however, that we have a suggestive and useful way of conceptualizing the space in which entrepreneurial activities unfold and an approach to expanding the frequently chaotic but fertile space in which innovative insight can flourish.

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Appendix

Elective Courses in Commerce (Undergraduate Business) and Economics

COMM 2010: Introduction to Financial Accounting
COMM 2020: Introduction to Management Accounting
COMM 2600/SOC 2600: Leadership across Disciplines
COMM 3410: Commercial Law I
COMM 3420: Commercial Law II
COMM 3600/ARAD 3100: Principles and Practices of Arts Administration
COMM 3660: Business of Consulting
COMM 3800: Business, Government, and Society
COMM 3810/RELG 2290: Business Ethics
COMM 3845: Foundations of International Business
COMM 4200: Project Management
COMM 4230/4777: Information Technology in Finance
COMM 4240: Electronic Commerce
COMM 4650: Business, Politics, and Culture in the European Union
COMM 4570: Topics in Finance: Investing in a Sustainable Future
COMM 4821: Managing Sustainability Development
COMM 4822: Investing in a Sustainable Future

ECON 2020: Principles of Economics: Macroeconomics
ECON/HIUS 2060: American Economic History
ECON 3030: Money and Banking
ECON 4210 International Trade: Theory & Policy
ECON 4350 Corporate Finance

Other Elective Courses Offered in the School of Engineering

APMA 3501: From Data to Knowledge (Special Topics in Applied Mathematics)

CE 4000: Construction Engineering
CE 4500: Introduction to Construction Management

CS 4753: Electronic Commerce Technologies

ENGR 1559: Business Fundamentals for Engineers
ENGR 4880: Business and Technical Leadership in Engineering
ENGR 4599: Business Intelligence

SYS 2057: Management of E-Commerce Systems
SYS 4000: Financial Aspects of Engineering
SYS 4044: Economics of Engineering Systems
SYS 5044: Economics of Engineering

Elective STS Courses

STS 1800: Business Fundamentals
STS 2700: Marketing for Engineers
STS 2730: Engineers and the Art of the Deal
STS 2740: Earth Systems Technology and Management
STS 2750: Engineers as Consultants
STS 2759: Special Topics in Engineering Business
STS 2760: Technology and Policy: Where Intent Meets Process
STS 2781: Making the Machine Age: Technology in American Society, 1890 - 1990
STS 2810: Introduction to Technology Entrepreneurship
STS 2820: Presentation Strategies for Entrepreneurs
STS 2830: Start-Up Operations for Entrepreneurs
STS 2840: Entrepreneurial Finance
STS 2850: Government and Entrepreneurship
STS 2860: Intellectual Property Engineering and Society
STS 2870: Scientific and Technological Thinking
STS 2880: Invention and Design
STS 2890: The Entrepreneur and History
STS 4810: New Product Development

Overview of the Technology Entrepreneurship Program

The Technology Entrepreneurship program, which is housed in the School of Engineering, coordinates a network of entrepreneurship-related programs and activities open to all students regardless of major or school within the institution. We start with the premise that there are two kinds of innovation: market-pull and knowledge-push. Market-pull innovations are those in which entrepreneurs identify a customer need first through customer discovery and then seek the technology required. Business schools traditionally focus on teaching entrepreneurs how to respond to market-pulls. Knowledge-pull innovations originate with an inventor or scientist; the entrepreneur then strives to connect the laboratory discovery and technical innovations with a customer need. We believe that knowledge-push innovations often lead to significant economic and social benefits. With that in mind, we designed our program to train engineering students to know how to recognize and convert discoveries into products; business schools are not well equipped to study and teach how to advance knowledge-push innovations.

The curriculum of the minor provides students with an education in and experience with the tools, techniques, and transformations involved in new venture development. For example: innovation and design (e.g., ideation, design thinking, problem solution fit), management and operations (e.g., team building, venture modeling), financial and social return (e.g., venture capital, venture philanthropy and impact investing), and legal dynamics (e.g., incorporation, term sheets, intellectual property). The new venture community is defined broadly to include not only startup companies, but also new ventures operating within or launched by established firms. Furthermore, this community is defined so as to include both not for profit and for profit ventures.

The curriculum of the Entrepreneurship Minor is depicted schematically below.