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Addressing academic researcher priorities through science and technology entrepreneurship education

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Abstract

A key feature of the movement to create more entrepreneurial universities is incentivizing researchers to move discoveries beyond the laboratory and into society. This places additional expectations on Ph.D. students and faculty in science and engineering disciplines, who are encouraged to explore the commercialization of their research to promote the role of universities in innovation and job creation. A major barrier to this movement is that traditional Ph.D. training does not prepare researchers to participate in entrepreneurial activity, and as such its relevance to scientific work may not be evident. In this paper, we propose a course model for science and technology entrepreneurship education that has been designed to enable academic researchers to play a more active and informed role in the commercialization of their discovery. Its curricular foundation is a set of 14 factors that address the following four priorities: (1) technology readiness and timing, (2) intellectual property pathway decisions, (3) engagement with the entrepreneurial ecosystem, and (4) personal career choices. We describe the rationale for the course, its content and outcomes.

Keywords Technology transfer · Entrepreneurship · Faculty · Graduate students · Research · Education

JEL Classification O3

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1 Introduction

Higher education is in a period of transformation. The global economy, the cost of a college degree, major shifts in consumer behavior, and new learning technologies are motivating universities to reconsider how they serve their stakeholders and contribute to economic development (Audretsch 2014; Barr et al. 2009). For research universities, one way to achieve this is by encouraging faculty and graduate students to translate their discoveries into patents and technology commercialization activities (Huang-Saad et al. 2017). This movement, dubbed "academic entrepreneurship" (Shane 2004; Wright 2007), is placing additional expectations on researchers who are increasingly compelled to explore the commercialization of novel research in order to promote the role of universities in innovation and job creation (Wright and Phan 2018).

To facilitate the transformation of academic research into innovations able to impact the economy and society, universities are making significant changes to their infrastructure, policies and programming. Institutional resources are being invested in technology transfer offices (TTOs), business incubators, accelerator programs, and early-stage seed funds (Barr et al. 2009; Huang-Saad et al. 2017). Technology transfer policies and licensing agreements are being streamlined to be more user-friendly (Valdivia 2013). Community members and alumni are being solicited to engage as mentors and investors in university startups. There is even discussion about recognizing commercialization activity in tenure and promotion processes (Sanberg et al. 2014), representing a dramatic change in what is expected of faculty researchers.

Although the intensive involvement of scientists is considered key to successful startups (Boh et al. 2016), there are significant barriers to getting more researchers involved. Most importantly, traditional Ph.D. training is not designed to prepare researchers to participate in entrepreneurial activity, and therefore its relevance to scientific work may not be evident (Gould 2015). Conventional science and technology entrepreneurship education (STEE) models often position the activity of commercialization (i.e., business) as separate from discovery (i.e., science), resulting in gaps in knowledge across disciplines (Libecap and Thursby 2008). Typically, STEE models involve researchers with technologies ready to be commercialized. As a result, while these provide valuable experiences for participants, they may not fully consider the distinct nature of early-stage commercialization, or the motives and interests of academic researchers.

The purpose of this paper is to propose a model of STEE through the development of a course that prepares researchers to engage in the identification, assessment, and pursuit of entrepreneurial opportunities while accounting for the priorities, constraints and culture of academic research. As a rationale for our model, we present the links (and gaps) between academic research and technology entrepreneurship based on the literature. We present the pedagogical and practical needs of researchers as they related to STEE. We also describe the content, learning outcomes, and present course evaluation data to demonstrate how the model can conceptually contribute to bridging the commercialization "valley of death." The use of the term "researcher" in this paper refers to faculty, graduate students, postdocs, scientists, and engineers involved in invention or innovation in a university setting.

2 Background

> Trading an experimental design for a business plan is not for everyone. The choice requires a careful examination of one's self and one's technology. It also requires learning an entirely new language. (Morrissey 2012)

2.1 University researchers and technology translation activity

STEE is an evolving area within universities that are committed to contributing to society not only through the education of students, but also through the commercialization of research resulting in new products and ventures (Barr et al. 2009; Rothaermel et al. 2007; Siegel and Wright 2015). Today, technology commercialization activities encompass “a broad range of activities, including startups, spinouts, licensing, collaboration, contract research, consulting and open innovation” (Nelson and Monsen 2014, p. 774). Many university stakeholders are involved in these activities, including teaching faculty, research faculty, graduate students, university administration, business development staff, and technology transfer offices (TTO) (Boh et al. 2016). Employers and communities also benefit from STEE through access to employees who are technically competent with a broad set of professional skills that enable them to collaborate, communicate, lead, manage shifting goals, and help them thrive (Duderstadt et al. 2005).

Given the importance of science and technology in economic development, the U.S. federal government actively supports university commercialization activities through legislation and programming. In 1980, the Bayh Dole Act allowed universities in the U.S. to own patents arising from federally-funded research. More recently, federal agencies, long considered the “lifeblood of university research” and the seedbed of U.S. innovation, are seeking even greater societal and financial returns from their investments in research (Morello 2013). For example, the National Science Foundation (NSF) through the I-Corps Program, is attempting to accelerate the translation from the laboratory to the market by bringing together scientists with business mentors to participate in intensive entrepreneurship training and market research (Morello 2013). Once formed, university startups are able to access competitive funding through other federal programs such as the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs (both dubbed “America’s Seed Fund”).

The objective of these initiatives is the cultivation of “academic entrepreneurs” or university scientists who engage in the commercialization of their research by patenting and creating businesses (Miller et al. 2018). They are based on the premise that most scientists lack an understanding of business and commercial opportunities, resulting in university startups that are more technology-driven, rather than market-driven (Druilhe and Garnsey 2004). University investments in STEE help bridge this gap, while also achieving other educational and recruiting goals. These investments are often accompanied by aggressive patenting strategies and policies to encourage collaboration and participation (Alper 2016; Phan et al. 2009). Collectively, the goal is to bridge what is referred to as the “valley of death” (Auerswald and Branscomb 2003), or the “institutional, financial, and skill gap” associated with the “transition from an existing or emerging technology to the creation of a compelling new market-driven business” (Barr et al. 2009, p. 371).

Financial returns from commercialization initiatives, which take years to develop, are still uncertain (Harrison and Leitch 2010; Siegel and Wright 2015). Annual technology transfer metrics – including patents, startups, and licensing revenue statistics – are the primary measures of success for institutions to date (Bradley et al. 2013). However, data indicate that few universities command significant licensing revenue from commercialization activities. Data also reveal that most technology transfer offices are cost centers for their universities and licensing revenue is strongly correlated to a university’s level of federal research funding (Valdivia 2013). Deciding which university inventions to support is challenging given lengthy development timelines and the high costs of maintaining patents (Alper 2016). Recently published research even questions whether university startup incubators positively contribute to innovation outcomes (Kolympiris and Klein 2017).

Despite these data, universities anticipate other, more indirect benefits from investments in technology entrepreneurship. These benefits take the form of partnerships and sponsored research agreements with industry partners that can help offset decreases in government support for research and operations, as well as position new technologies for commercialization through existing companies (Miller et al. 2018; Phan et al. 2009). They can include improved teaching, research, job placement, recruitment and retention of faculty and students (Biancamano 2002), as well as overall prestige for the institution (Abreu and Grinevich 2013). Finally, universities can benefit from the public relations opportunities that arise from the launch of innovative technologies, products, and services.

2.2 Academic researchers and STEE

Minimal scholarly attention has been paid to Ph.D. training in the area of technology entrepreneurship (Dooley and Kenny 2015; Williams et al. 2013). Scholars point out that "top down" institutional approaches to technology commercialization may overlook "nuanced differences in the goals, motives, and experiences of academic scientists" (Hmieleski and Powell 2018, p. 44). It is recognized that the culture of research universities, where the educational model typically isolates scientists in their respective academic disciplines, limits access to STEE (Garcia-Martinez 2014). For instance, graduate students in STEM fields report they are able to spend only 1–3 h per week on professional development outside of their research and teaching responsibilities (Wheadon and Duval-Couetil 2014). In contrast, semester-long courses in STEE can require 9–12 h per week, and participation in a highly structured commercialization programs such as NSF I-Corps, far more.

Nevertheless, science and engineering disciplines are recognizing that some business education is necessary to adequately prepare students for contemporary career paths given that 50% or more Ph.D. graduates are likely to be employed in business, government, and nonprofit sectors (Amsen 2011; Sauermann and Roach 2012; Turk-Bicakci et al. 2014). The employers hiring Ph.Ds. indicate they expect well-rounded disciplinary experts who are able to generate "real-world" value from knowledge and research (Wendler et al. 2010). Often, these well-rounded experts are referred to as T-shaped professionals, a metaphor used to describe people in the workforce who have a depth of expertise in a single field as well as the ability to collaborate across disciplines (Barile et al. 2015). It has been suggested that entrepreneurship education can be an efficient and effective way to build the transferable skills that are necessary for employment in both academic and non-academic contexts (Duval-Couetil and Wheadon 2014).

Some specific challenges and gaps in knowledge faced by academic entrepreneurs have been described by scholars and administrators (Biancamano 2001, 2002; Love 2013; Slaughter et al. 2002). We have found that faculty and graduate students often participate in commercialization activities (protecting intellectual property, negotiating licensing agreements) with only a surface-level understanding of potential conflicts, resources, and entities that might protect their interests at different points throughout the process (Biancamano 2001, 2002; Slaughter et al. 2002). In some cases, researchers are required to form companies (i.e., legal entities) in order to have access to university resources and funding for commercialization. Many underestimate the business expertise required and rely heavily on the advice of TTO staff and business mentors. A summary of common challenges are presented in Table 1.

2.3 STEE models involving researchers

Business schools traditionally play a significant role in developing STEE models as a means to “fill the gap in the expertise of TTOs and to overcome the lack of surrogate entrepreneurs” (Wright et al. 2009). However, some note that the scope of knowledge and talent required for both STEE education and technology entrepreneurship is growing with the emergence of new business models (Wirtz et al. 2016), new forms of capital (Bruton et al. 2015), and a wider variety of stakeholders (Huang-Saad et al. 2018; Markman et al. 2008). Given the breadth of technology entrepreneurship activities and the nature of early-stage university research, it has been said that “developing educational resources for technology commercialization is not as simple as repackaging an existing entrepreneurship or new product development course” (Nelson and Monsen 2014, p. 774).

Barr et al. (2009) described STEE as fitting within the scope of general entrepreneurship education pedagogy, but relying on “existing and emerging technologies as the platform for entrepreneurship learning” (p. 372). The academic field of entrepreneurship education tends to differentiate course and program offerings based on whether they are “education about entrepreneurship” (i.e., learning) or “education for entrepreneurship” (i.e., doing) (Laukkanen 2000). Similarly, (Falkäng and Alberti 2000) distinguished between: (1) courses that explain entrepreneurship and its importance to the economy, in which students are at a distance from the subject; and (2) courses with an experiential component that develop in students the skills necessary to develop their own businesses. Within this context, Barr et al. (2009) identified the challenges of teaching STEE given its various stakeholders and outcomes – distinguishing between programs designed to “facilitate the creation of technologies” (characterized as a “major university effort”), from those designed to increase “student skills in technology entrepreneurship” (an educational outcome) (p. 372).

Many conventional STEE models directed at graduate student researchers fall into the experiential category (i.e., “education for entrepreneurship”) as they focus on developing plans for commercialization-ready technologies. An example is Georgia Tech’s Technological Innovation: Generating Economic Results (TI:GER) Program, which assembles teams of MBA and law students to focus on the commercialization of a Ph.D. student’s research (Thursby et al. 2009). Another is North Carolina State

Table 1 Challenges related to student and faculty involvement in technology commercialization and entrepreneurship (*source*: authors)

Challenges for faculty and institutions	Challenges for graduate students
Questions related to conflicts of interest and research integrity	Maintaining focus on dissertation research while being involved in a startup
Managing time commitments to both the university and venture	Avoiding conflicts between thesis research and research benefitting a new company
Allocating institutional resources and external funding support for research vs. business ventures	Navigating academic pursuits (publishing) when students become involved in a faculty startup (patenting)
Managing relationships with academic colleagues in order to maintain the collegial sharing of research	Maintaining healthy mentee/mentor relationships with faculty advisors
Managing the consequences of changes in research focus, from basic research to technology development	Navigating employer/employee relationships with faculty advisors
	Recognizing student contributions in inventorship and ownership agreements

University's Technology Entrepreneurship and Commercialization Program (TEC), an interdisciplinary, business school-based program "equally valuable for those seeking to start a new company based on an innovative technology and for those working within an established firm to bring new technologies to the marketplace" (NSCU website). Other models include fellowship programs which select students on a competitive basis to spend a fully-funded semester and summer working with a mentor on a commercialization plan (Cornell University), and competition-based programs, which offer the experience of creating business plans and pitching to investors.

Common STEE experiential course models bring together graduate students from business and STEM fields to examine the commercialization needs of technologies provided by a researcher or university TTO. Course topics or modules typically mirror a linear process associated with university commercialization activities, including product/idea generation, product/technology description, prioritization, summarization, product definition, marketing description, and culminating in a go/no-go decision regarding further development (Siegel et al. 2003). The NSF I-Corps program is based on a similar premise, but places heavy emphasis on the collection of primary market data that is used to "pivot" some aspect of the business model in a fundamental way (Blank and Dorf 2012). I-Corps teams have three primary members: a technical lead (researcher), entrepreneurial lead (student), and an I-Corps mentor (business person) who are required to conduct 100 interviews with potential customers and industry experts to develop a value proposition and commercialization strategy. Graduate students and postdocs are encouraged to be the "entrepreneurial lead" for these teams, given their knowledge of the technologies and stake in exploring their commercial potential.

Research suggests that these types of authentic, interdisciplinary, and immersive experiences can bridge the transition from an idea or concept to the introduction of product for those who choose to participate (Barr et al. 2009; Thursby et al. 2009). They benefit scientists and engineers who, without training, may be less likely to engage in commercialization. They also provide aspects of business education that prepare scientists for management roles early in their careers (Barr et al. 2009).

However, some scholars have indicated that too much emphasis on practical experience may have negative consequences because "the mental models that such pedagogies create can quickly become obsolete, particularly in light of the fast evolving technologies the curricula are supposed to address" (Locke and Schöne 2004, p. 332). This means that these immersive experiences may inspire students to become more entrepreneurially-oriented, but neglect their development of "critical thinking skills, such as the ability to assess risk, and recognize the inevitable downsides of entrepreneurial activity" (Phan et al. 2009, p. 332). Generally speaking, there is a lack of research on the effectiveness of STEE models (Libecap and Thursby 2008, p. 2), mirroring the field of entrepreneurship education more generally (Duval-Couetil 2013; Fayolle and Gailly 2015; Rideout and Gray 2013).

2.4 Researcher priorities

> In business, you often need to make educated guesses. This is hard for scientists, who are used to making evidence-based predictions. (Pierce 2008)

Bringing an invention through to company formation requires a different mindset and set of skills than those cultivated through basic research. It has been said that organizations and stakeholders involved in technology transfer and product innovation have different "thought worlds" (Dougherty 1992, p. 179) with distinct languages and routines that influence technology transfer outcomes (Siegel et al. 2003). Similarly, researchers and business people have different values, knowledge bases, viewpoints, and motives. For example, scientists and engineers are accustomed to making "evidence-based predictions" (Pierce 2008) given that science is a process to determine what is factual, requiring impartial objectivity that should not be influenced by particular perspectives, value commitments, community biases, or personal interests (Reiss and Sprenger 2014). In contrast, business management is the organization, supervision, or direction of a thing or person (Oxford English Dictionary, 2007), which may or may not use science to serve a social, political, or economic need. Business decisions are data driven but are often made with incomplete information, and can be influenced by stakeholder interests (Mintzberg et al. 1976).

Researcher interest in STEE can be influenced by social norms within respective academic disciplines or communities of practice, which influence participation. Social Cognitive Career Theory (SCCT) (Lent et al. 2000) and Social Learning Theory (Krumboltz et al. 1976) serve as useful lenses through which to examine STEE education at an individual researcher level. SCCT represents the interplay of social cognitive variables, such as self-efficacy (Bandura 1986), with other personal, contextual, and experiential factors that influence: (1) how basic academic and career interests develop; (2) how educational and career choices are made; and (3) how academic and career success is achieved. Social Learning Theory addresses how perceptions of value and relevance are transferred through the process of 'enculturation' via a students' community of practice (their discipline, department, and advisor). Within these communities of practice, it is not the acquisition of knowledge or skill (e.g., textbook knowledge) that identifies the "competent" member. Instead, the ability to "read" the local context and "act in ways that are recognized and valued by other members of the immediate community of practice" is all-important. (Contu and Willmott 2003, p. 285).

From a curricular perspective, STEE tends to focus on understanding the innovation strategies of larger firms, whereas institutional levels of analyses (firms, universities, government agencies) and the individual level of analysis (scientists, technology managers, and entrepreneurs) have not been explored (Phan et al. 2009). As described above, social influence and role models can legitimize entrepreneurial activities (Miller et al. 2018). Institutional and departmental norms and incentives play a role (Rothaermel et al. 2007). And, day-to-day responsibilities including discovery, teaching, grant-writing, and publishing must be considered in STEE courses directed at graduate students or faculty. These individual-level factors and micro-level processes that influence participation in academic entrepreneurship are gaining more attention as interest in academic entrepreneurship grows (Balven et al. 2018).

3 A STEE model for academic researchers

Academic entrepreneurs must possess a rare blend of skills. They must have the attributes of traditional scientists, including inner drive, rigor, and technical skills. They must also possess the attributes of traditional entrepreneurs, such as the abil-

> ity to recognize business opportunities and create value for the customer, and the willingness to take risks (Garcia-Martinez 2014).

The model of STEE we are describing in this paper was first piloted in 2011 when one of the authors wanted to share his experience after taking a multi-year, part-time leave of absence from his faculty position to serve as the Chief Technology Officer for a university-based startup acquired by another early-stage company, that was ultimately acquired by an established corporation. As a scientist, he wanted to share what it took to move a new technology from a laboratory prototype stage to commercialization. Lacking extensive knowledge of entrepreneurship course offerings at the university, he teamed up with the other co-author to explore options. At the time, most entrepreneurship courses at our university were being taught primarily from a business perspective, which gave us the opportunity to develop a course specifically for scientists and engineers interested in the commercialization of research.

3.1 Course objectives

We developed the course to complement other university initiatives by tailoring it to the interests and needs of academic researchers, including: (1) the distinct nature of early-stage commercialization, which is characterized by multi-year timelines, high levels of investment, and complex decisions related to commercialization strategies; and (2) the reality that involvement in entrepreneurship requires attention to many professional and personal considerations, including publishing/patenting, conflicts of interest, legal commitments, financial implications, time management, and work-life balance. The vision was to better prepare researchers for near-term or future participation in commercialization by leveraging the personal stories of experienced academic entrepreneurs and experts who would highlight windows of opportunity and guide participants' understanding of the steps involved.

To clearly differentiate our course from other campus offerings and its emphasis on university-based startups, we titled the course: "Life of a Faculty Entrepreneur: Discovery, Development & Translation" (abbreviated as LFE). The purpose as stated in the syllabus is (see Appendix 1):

> The intent of the course is to complement graduate student research activities and not detract from them in terms of content and time. Students are challenged to think systematically and analytically about processes that move research beyond publications, papers, and patents in order to initiate commercialization. We do not expect that all participants will have a technology that is ready for commercialization, which is often the case in other programs. Rather, our goal is to provide frameworks that will help university entrepreneurs define possible entry points to the commercialization process, and determine their best options prior to getting started.

3.2 Contribute to bridging the commercialization "Valley of Death"

As conceptually illustrated in Fig. 1, the ultimate goal of the class is to contribute to bridging the commercialization "valley of death" by preparing scientists to engage in translation activities in ways that address both their research and career goals. We achieve this by developing in students a greater understanding of technology readiness and timing; IP and commercialization pathways; stakeholders in the entrepreneurial ecosystem; and potential career impacts. Our goal is to prepare researchers for intensive, hands-on commercialization activities such as I-Corps, the launch of a new venture, or the licensing of technology to an established organization. We expect that participating in the course will enable them to drive strategy where their technology is concerned, thereby reducing inefficiencies and risks associated with academic entrepreneurship over the long term.

3.3 Curricular foundation: factors to address researcher priorities in STEE

The curricular foundation of the course is a set of 14 factors pertinent to STEE that we refined over seven years of teaching the LFE course (Table 2). The factors focus heavily on the development of technology, while also integrating critical thinking related to the business, legal, career, and personal decisions necessary during each stage. They were derived from conventional entrepreneurship curriculum (Blank and Dorf 2012; Duening et al. 2014; Osterwalder and Pigneur 2010), research, case studies, and lectures by faculty entrepreneurs and technology commercialization stakeholders experienced in emerging technologies and early stage companies. We took copious notes during lectures by faculty entrepreneurs and other stakeholders to summarize important concepts, challenges and decisions. Feedback from students and alumni was solicited and incorporated into subsequent years' course materials. The course materials proceeded through seven cycles of development in order to yield a consistent set of topics that aligned with the needs of students and course objectives.

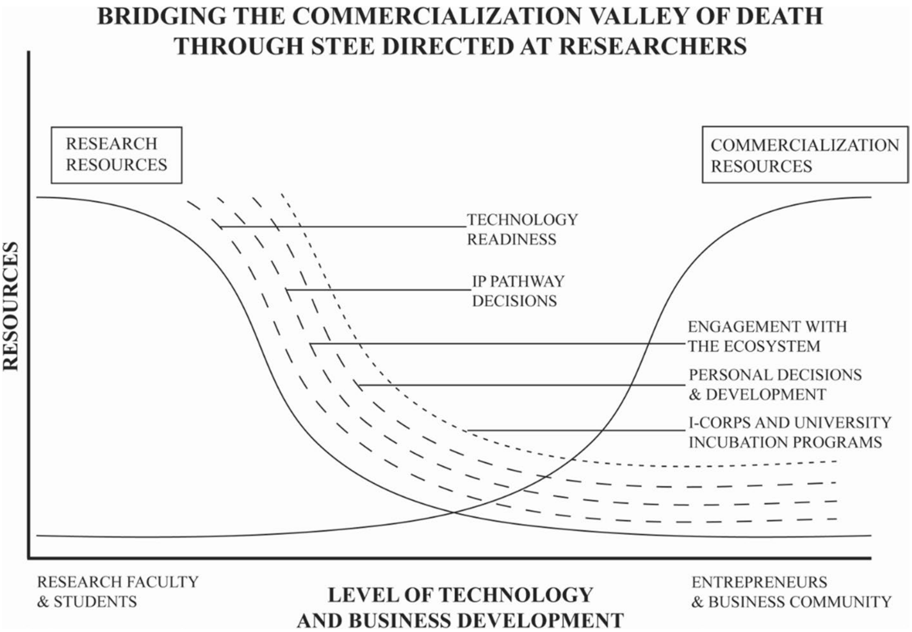

Fig. 1 Bridging the "valley of death" through STEE directed at researchers (conceptual)

Table 2 14 factors to address researcher priorities in STEE

	Factor	Topics
I Technology readiness and timing		
1	*Proof of concept vs. actual prototypes* There is a difference between an idea (university research), a business opportunity (with market validation), and a sustainable business venture (with revenues and profits)	Importance of prototypes to credibility Validation of market needs and wants The role of perfectionism in science versus pragmatism in business
2	*Timing: When to move up and when to move on?* There are three aspects of timing that are pertinent to commercialization within the university: (1) technology readiness; (2) market readiness; and (3) career readiness	Knowing when one has a patentable technology (and when one does not) Differences in technology sectors, stages of research, and time to market (e.g., healthcare versus software, basic vs. applied research) Context and environmental trends (e.g., energy policy, climate change) Availability of funding
3	*Need for research discipline to achieve reproducibility of results and product robustness* The characteristics of the technology discipline must align with a viable business model to meet customer needs and generate revenue.	Companies built around one product vs. platform technologies (multiple products) Business model components: revenue sources, cost drivers, investment size, and key success factors Business decisions and tradeoffs Evolution of business models over time due to competitive factors and trends
II. Intellectual property (IP) pathway decisions		
4	*Disclosures, provisional patents, patents, and publications* How to minimize conflicts between patenting and timely publication	Purpose/mission of university technology commercialization activities Services of technology transfer offices Invention disclosure processes Milestones The need for speed

Table 2 (continued)

	Factor	Topics
5	*Freedom to operate analysis* Obtaining a legal opinion on whether the making, using, selling, or importing of a product/technology, in a given geographic market, at a given time, is free from potential IP infringement can be an important investment step for a university startup.	Stage of development at which to seek freedom to operate analysis Introduction to IP strategies
6	*Defining pathway (license vs. startup)* Circumstances under which startups can provide better returns than established companies in terms of revenue and sponsored research.	Stage and nature of technology development IP status Attractiveness to potential partners Availability of startup funding and resources Creating a legal business entity Founders' agreements and contracts Exit strategies
III. Engagement with the entrepreneurial ecosystem		
7	*Role of the entrepreneurial ecosystem and networking* Researchers should find mentors who provide qualified advice and open doors.	Entrepreneurial networks Alums, mentors, colleagues Roles of attorneys, accountants, consultants, and other service providers
8	*Building a business team to move from prototype to product* A wide range of talent is required identify markets, resources, partners, and potential revenue streams.	Finding expertise to lead the process Soliciting feedback from users and potential customers related to buying decisions Conducting primary and secondary market research Competitive analysis
9	*Sources of corporate and project capital versus organic growth* The type of capital required will depend on the type of venture being built, its stage of development, and capital needs.	University or public sources of funding (seed funds, NSF I-Corps, SBIR, and STTR) Bootstrapping vs. private sources of capital (friends and family) and angel investors Venture capital Bank financing/loan guarantees Corporate (strategic) partnerships

Table 2 (continued)

	Factor	Topics
10	*Understanding investors* Venture capitalists are a significant source of funding for technology startups and often provide business development value to startups beyond money.	How venture capital works What to expect when seeking venture capital and partnering with investors Term sheets Corporate Board Structure Negotiation
11	*Effective communication* Success as an entrepreneur is determined in large part by one's ability to communicate.	Effective communication for different audiences (scientific versus business) Formats for presentations and pitches Oral versus written communication
IV. Personal decisions and career development		
12	*Managing conflicts of interest* Faculty involvement in commercialization changes their relationship to the institution.	University conflict-of-interest policies Ethics Disclosure and approval procedures Use of university resources Impact on research (direction/integrity) Impact on student advising
13	*Financial and personal costs (and benefits) to founders of new venture* Faculty involvement in commercialization and startup activities impacts their relationship with the institution as well as their associated responsibilities.	Factors to consider: goals, resources, time, talent, risk tolerance, and rewards Impact on publishing, tenure, and promotion Relationships with administrators, peers, and students Maintaining balance
14	*Leadership* Entrepreneurship requires inspiring the team with vision, energy, and insight to achieve a common goal	Skillset associated with being an inventor/innovator versus a CEO Identifying and attracting talent

The 14 factors focus on concepts and use language intended to address researcher priorities. They are organized into four categories: (1) Technology Readiness and Timing; (2) IP Pathway Decisions; (3) Engagement with the Entrepreneurial Ecosystem; and (4) Personal Decisions and Career Development. The categories and factors are not presented in this linear order in the classroom. Instead, they are interspersed throughout the semester as students move from learning "about" each (understanding concepts) to higher order levels of thinking, including application, analysis, and evaluation that enable them to make commercialization decisions and formulate plans (Anderson et al. 2001). Students repeatedly encounter these themes throughout the semester as they consider the application of these topics to their own research and careers.

To reinforce the business knowledge and literacy pertinent to technology entrepreneurship, readings address topics related to venture capital, business models, competitive market analysis, business team building, fund raising, and exit strategies. Readings and videos from *Harvard Business Review*, *The Wall Street Journal*, *Science*, and *Nature* serve as the foundation for discussions on technology-based businesses, business models, investments, and leadership. Scholarly articles related to academic entrepreneurship foster critical thinking and discussion on academic entrepreneurship, research, and career choices (Appendix 1). These examine metrics related to faculty involvement, return on investment, and more philosophical questions related to scientist and university involvement in business.

3.4 Course format

The format is a 16-week course that meets one evening per week for approximately 3 h. It is a credit-bearing academic course in which students must formally enroll, differentiating it from non-credit workshops designed to spur involvement in technology commercialization and entrepreneurship. Anchoring the course firmly in the academic space was intentional as a way to emphasize the learning objectives and skill development (educational metrics), rather than advancing the commercialization of a particular technology (commercialization metrics). Faculty, post-docs, and research scientists do not typically register for credit, however, they agree to attend all course lectures and complete all assignments. Often, these more experienced course participants serve as team members on commercialization projects and provide an important element of mentorship for graduate students.

Faculty entrepreneurs contribute as speakers, representing a variety of academic disciplines and stages of the commercialization process – from early-stage licensing negotiations to startups that have been acquired by larger companies. Their experiences are presented as real-world case studies and we encourage them to speak candidly. Students are also introduced to the entrepreneurial ecosystem via presentations from TTO staff, IP and business formation attorneys, venture capitalists, valuation specialists, and a market research librarian.

3.5 Instructional approach and assignments

The course follows a "mixed methods" instructional approach as it teaches entrepreneurship and its importance via lectures and discussion, while also including an experiential component. Assignments foster critical thinking and collaborative learning. Two reflection papers require students to apply the 14 factors and what they have learned in classroom lectures, and directed readings. One reflection paper is focused on their own research, and the other is based on the case study of an emerging technology selected by the instructors, the latter requiring that students consider and analyze commercialization strategies in an area outside of their own field.

Students also have the experience of working as a team on a commercialization plan for translating a specific technology. The project consists of developing a pitch deck, presentation and an extended executive summary. Teams are comprised of two to three people, ideally from different disciplines. The focus of the project is a technology in which one of the team members is involved, or one of common interest to the team. The project emphasizes "front end" of commercialization (e.g., technology assessment, IP pathway, and business model) and effectively communicating this to stakeholders, rather than reaching "go/no go" commercialization decisions. Nevertheless, teams are encouraged to propose various operational and exit strategies, when appropriate.

4 Course evaluation and impact

> Graduate students and postdoctoral fellows are not taught to recognize and appreciate the skillset they develop. Nevertheless, that skillset is there, and it is entirely applicable to business. Grant applications are business plans, seminars are business pitches, and the competencies developed managing personnel (such as co-op and summer students, technicians, co-workers and mentors), accommodating budgetary requirements (such as grants, laboratory/operating costs, consumables, travel and salaries), establishing and negotiating collaborations, and meeting deadlines are all directly transferable to the board room. (Thon 2014)

To assess the impact of the course and guide its development over the past seven years, we collected course evaluation data through entry and exit surveys to explore changes in participants' entrepreneurial intention, self-efficacy, value of the course, and contributions to career development. Over seven semesters, 183 faculty members and students participated in the course, which is offered once per year. Our results are based on 129 participants who completed both the course entry and exit surveys over this period. It is important to note that we collected data related to educational evaluation objectives (e.g., judge the merit and worth of the course, make decisions about improvements, and provide information to stakeholders) rather than to meet research objectives (Mathison 2008). To evaluate the impact of the course, and how well it met its stated objectives, we explored the following questions: (1) To what extent did participants' entrepreneurial self-efficacy and entrepreneurial intention change as a result of the course? (2) To what extent did participants value the course model?

4.1 Participants

The characteristics of course participants are presented in Table 3. Most (72.1%) were Ph.D. students, from engineering and the sciences, which reflected our intended population. Less than 20% had any experience with commercialization, but almost one quarter were in the process of protecting intellectual property. Over a third (44.2%) had worked in industry, two-thirds knew someone who started a venture, and almost half knew a faculty member who started a venture.

Table 3 Participant information

		Frequency	Percent
Roles	Master's	25	19.4
	Ph.D.	93	72.1
	Post-Doctoral	2	1.6
	Faculty	9	7.0
Department	Agricultural and Biological Engineering	27	20.9
	Electrical and Computer Engineering	13	10.1
	Mechanical Engineering	10	7.8
	Civil Engineering	7	5.4
	Computer Science	7	5.4
	Technology	6	4.7
	Industrial Engineering	4	3.1
	Chemistry	4	3.1
Plan to commercialize	Yes	36	27.9
	Maybe	62	48.1
	No	28	21.7

4.2 Evaluation measures

4.2.1 Entrepreneurial self-efficacy and entrepreneurial intention

To evaluate the course, we examined participants' *entrepreneurial self-efficacy* (ESE) and *entrepreneurial intention* (EI), which are considered to be desirable entrepreneurship education outcomes (Rideout and Gray 2013). ESE refers to the confidence someone has in his or her ability to perform the roles and tasks of an entrepreneur (Zhao et al. 2005) and EI refers to attitudes toward entrepreneurship that ultimately lead to the establishment of new ventures (Bird 1988; Kolvereid 1996). These two constructs, in particular, are widely used to evaluate impact of entrepreneurship education in university settings, given that intention and self-efficacy precede actual behaviors and are modified by educational experiences (Ajzen 1991).

In our pre- and post-course surveys, we used two ESE subscales that comprise the V*enturing and Technology Self-Efficacy Scale* (Lucas et al. 2009). These are specific to technology-based entrepreneurship and most pertinent to our population of scientists and engineers. The scale measures self-confidence associated with tasks performed in managerial, entrepreneurial, and technical-functional roles. It encompasses two constructs: *venturing self-efficacy* (VSE) and *technical-functional self-efficacy* (TSE). VSE represents the confidence in one's ability to perform the managerial tasks of entrepreneurship (e.g., "know the steps needed to place a financial value on a new business venture"). TSE represents the confidence in one's ability to perform the tasks associated with using new science and technology in innovation (e.g., "convert a useful scientific advance into a practical application"). In pre- and post-surveys, participants were asked to rate their confidence on a scale of 0–10 (*0% not at all confident* to *100% completely confident*) as described by Lucas et al. (2009). The internal consistency (Cronbach's *a*) for both pre- and post- sub-scales was =0.92–0.94 and we used the average scores for each sub-scale as recommended by Lucas and his colleagues (2009).

EI has been described as a “loosely defined construct” (Thompson 2009, p. 133), encompassing a range of behaviors, attitudes, and precursors to entrepreneurial activity (Bird 1988; Kolvereid 1996), as well as career orientation and vocational aspirations (Thompson 2009; Valliere 2015). To assess EI for course evaluation purposes, we asked participants the extent to which they were interested in “starting a venture of their own within the next five years” (short-term intention) and “starting a venture of their own in 5+years” (long-term intention) using a 4-point Likert scale (*1*=not at all interested; *4*=very interested).

4.2.2 Value of the course model to participants

To assess the value of the course to participants, data were gathered through more conventional quantitative and qualitative questions used in course and program evaluation. These focused on perceived gains in knowledge, general satisfaction, and the degree to which participants felt the course would be useful to their careers.

4.3 Data analysis

To assess the changes in pre- and post-measures of self-efficacy and intention, we used paired t-tests and calculated effect sizes (Cohen’s d) based on the formulas of Borenstein et al. (2009). To examine the relationship between changes in ESE and EI in more depth, we used multinomial logistic regression models to examine if three different patterns of change in EI (i.e., increase or maximum score at pre- and post-survey, no change, decrease over time) were associated with changes in VSE, TSE and prior experiences in entrepreneurial activities. Given the ceiling effect, participants who indicated maximum scores (*very interested)* at both the pre- and post-survey were included in the “increase” group. The reference group was the “decrease” group for whom entrepreneurial intention decreased from pre- to post-course survey.

Descriptive statistics were used to summarize responses to other course evaluation survey items. Patterns in responses to qualitative questions were examined to assess the value of the course model.

5 Results

5.1 Changes in entrepreneurial self-efficacy and entrepreneurial intention

Increases in ESE resulting from the course were significant. Table 4 shows that paired comparisons of pre- and post-course survey responses were 4.93–7.85 for *venturing self-efficacy,* $t=16.57$, $p<.001$, $d=1.54$ and 6.89–8.93 for *technology-functional self-efficacy*, $t=12.05$, $p<.001$, $d=1.15$, indicating that participants made significant gains in their confidence associated with both technology-development and the business-related tasks pertinent to STEE (see individual item results for the scales in Appendix 2). The pre-survey results show that most were interested in starting a venture after five years, which aligned well with the intended audience for the course. The post-survey results show only minor changes in intention at the conclusion of the class. The most significant change in pre- and

Table 4 Pre and post changes in venturing and technology self-efficacy and entrepreneurial intention

	Range	*Mean (SD)*		*t*	d^{+}
		Pre	Post		
Venturing self-efficacy	0–10	4.93 (2.17)	7.89 (1.56)	16.57***	1.54
Technology-functional self-efficacy	0–10	6.89 (2.11)	8.93 (1.38)	12.05***	1.15
Entrepreneurial intention (short-term)	1–4	3.37 (0.84)	3.14 (0.86)	−2.98**	−0.27
Entrepreneurial intention (long-term)	1–4	3.58 (0.69)	3.61 (0.58)	0.51	0.04

***<.001; **<.01

+Effect sizes (*d*) were calculated using the Morris and DeShon (2002) equation

post- responses was for the item "start a venture within five years," where participants were "very interested" in doing so during the first class session, but their intention decreased at the end of the course ($t=-2.98$, $p<0.01$, $d=-0.27$). This aligned with our expectations for the course and with research suggesting that entrepreneurship education allows students to better assess whether they should pursue an entrepreneurial career, differing notably from "the implicit notion that entrepreneurship education somehow enhances students' willingness to become entrepreneurs" (Von Graevenitz et al. Weber 2010, p. 91). It is very possible that participants' entrepreneurial intention was tempered by a realization of the complexities associated with technology entrepreneurship.

Table 5 shows the results for the multinominal logistic regression models. Participants for whom VSE increased (managerial tasks associated with entrepreneurship), were less likely to decrease their short-term EI ($\beta=0.36$, $SE=.18$, $p<.05$, $OR=1.43$). No other predictors could significantly differentiate between participants whose short-term EI increased and those for whom it decreased. However, in terms of long-term EI, TSE was associated in a negative way. Participants for whom TSE increased, intention to start a business after five years decreased ($\beta=-0.43$, $SE=.20$, $p<.05$, $OR=0.65$) or did not change ($\beta=-0.48$, $SE=.24$, $p<.05$, $OR=0.62$). This indicates that the course reinforced the desire to start a business in the short term for those who were wishing to do so at the start of the class, and whose confidence in the managerial tasks associated with entrepreneurship grew. For those

Table 5 Multinomial logistic regression models

	Constant			Increase		
	β	SE	OR	*β*	SE	OR
Short-term intention						
Intercept	−.77	.46		.00	.37	
Prior experiences	.01	.13	1.01	−.09	.11	
Difference in VSE	.36*	.18	1.43	.27	.15	1.31
Difference in TSE	−.30	.19	0.74	−.17	.16	0.84
Long-term intention						
Intercept	−.13	.60		1.57	.46	
Prior experiences	.10	.17	1.11	−.02	.13	.98
Difference in VSE	.42	.24	1.52	.32	.19	1.38
Difference in TSE	−.48*	.24	.62	−.43*	.20	.65

*<.01

who had greater gains in confidence in science and technology tasks, the desire to start a business did not change or lessened, even in the long term. This implies that for those who felt more confident in the science and technology tasks, the course reinforced the role(s) they wanted to play in technology venturing and it was not solely to start a business. It may also indicate that respondents had gained a better understanding of both technology and business roles and requirements.

5.2 Value of the course to participants

Of the 129 participants surveyed, 88% agreed that the knowledge and skills gained in the course would be useful to their future careers. They reported gains in their knowledge related to a number of topics, the greatest being for *managing research and innovation for commercialization*, *the role of faculty member or scientist in a startup*, *sources of funding for new ventures*, and *entrepreneurial communication*. Fifty-six percent indicated they were likely to participate in other entrepreneurship-related courses in the future.

Responses to qualitative exit survey questions are presented in Table 6. These statements indicate learning gains and a high level of satisfaction with the course and the experience of learning among a community of individuals with similar experiences. The 14 factors and the manner in which the topics were interspersed throughout the semester was perceived as an effective curricular model for our target audience. The candid stories from faculty entrepreneurs gave students a window into "real" experiences, good and bad. Student feedback reflects the positive impact the course had on their professional development, personal development, and motivation.

The course's potential to prepare participants for technology commercialization activity is suggested in survey comments. Participants made connections between the concepts covered in the course and the experiences of academic researchers involved in entrepreneurial activity. It motivated them to think about possible pathways for research beyond scholarly work. Participants felt that working on experiential team projects contributed to their business literacy and gave them the experience of writing and communicating in a different style. It also helped them understand the perspectives and objectives of various commercialization stakeholders with the entrepreneurial ecosystem, and how these aligned with their own personal and professional goals.

6 Discussion

> The activity of commercialization is actually separate from doing science. The science can be very dispassionate—the reaction either worked or not. But how you sell it and position it and handle it, that's a completely human endeavor (Judith Giordan in Morrissey 2012).

The purpose of this paper was to present a model for structuring STEE in a manner that addresses the priorities of scientific work and the interests of academic researchers to enable them to engage in technology commercialization and entrepreneurship activities. We propose that educating researchers prior to their engagement in commercialization activity,

Table 6 Representative comments from course exit surveys

Category	Quotes from participants
Effectiveness of course format and 14 factors	The variety of experienced speakers seemed to complement the learning process very well! If there exists a "correct" order for the presentations, this was it.
	The speakers all have different insights about their cases and after hearing many of them, connections between what they were saying, the readings, and other material started to emerge.
	Having experts come in and give testimony to their experience. It's difficult to put a value on the opportunity to have an open floor Q and A session with respected professionals.
	When the implications of research are twenty years down the road, it can be difficult to see the end result, and understand how it will benefit people. However, in this class, we have learned how to have people in mind during the entire research process. This makes the research problems more realistic.
Shared experience and community of practice	It afforded me the chance to come into a class with an engineering/science background and learn through people of similar backgrounds how entrepreneurship works. Being able to learn through the experiences of other people in an intimate class setting is invaluable and I do not think I could have had the same opportunity in any other department or school.
	This course offered me great opportunities to communicate with people doing real business with an academic background. Their experience is quite different from those of traditional businessman. Also the course is well organized so that at the end of semester, many faculty and students get to know each other or even become friends.
Effectiveness of experiential team project	This course led me to write a business plan as a term project, which is really important and necessary for further developing my ideas and facilitating the next step.
	I'm also glad we worked on a business plan outline, I think it was an excellent project to start to work on and get our hands a little dirty with.
Critical thinking and decision-making	It showed me that starting my own business is not my preferred strategy. It showed me that the amount of money required to start my own business is quite huge, though the amount of money required to merely license a technology is more approachable.
	The ideas and thoughts related to business, different from science, this will keep the diversity of my thinking…
Positive impact on professional development	The whole process for a startup is very useful. In addition, I learned the importance of the soft power of social skills and networking.
	To know that being an entrepreneur is not impossible, and what it takes to be an entrepreneur.
	I liked how motivated I felt after leaving class.

better prepares them to interact with TTOs, IP attorneys, and business development professionals. The main goal of our model is to help academic researchers manage or avoid common challenges related to student and faculty involvement in technology commercialization (Table 1), which we propose can contribute to a more efficient use of university commercialization resources over the long term. The model centers on the importance of researcher involvement in the technology commercialization process, given that business faculty, MBA students, and incubator staff may have limited knowledge of specific technologies, as well as different metrics for success. The model also provides participants new perspectives on their research and career choices through a greater understanding of their personal and professional interests as they relate to technology entrepreneurship.

Fayolle and Gailly (2008) state that entrepreneurship education "should be designed through a thorough understanding of the profile and background of the audience, particularly in terms of prior entrepreneurial exposure" (p. 577). Accordingly, this model of STEE is grounded in evidence that the intensive involvement of scientists is key to successful startups (Hsu et al. 2007). It also reflects the fact that only a small number of students and faculty work on research with immediate commercial potential, and many are interested only in acquiring knowledge and skills (Barr et al. 2009). As such, this model develops entrepreneurial attitudes and skills, independent of those directly related to the creation of new ventures (Fayolle and Gailly 2008). It also contributes to the development of boundary-spanning behaviors that are increasingly valued in careers where both business and technology are important including use of non-technical communication, experience working in multidisciplinary teams, and understanding market forces and customer needs (Barr et al. 2009).

Our goal was to differentiate our course from conventional STEE models, where scientists contribute the technology but largely rely on legal and business experts for decision-making related to commercial development. We addressed some of the limitations of conventional models described in the STEE literature, particularly those associated with bringing together people from different disciplines, with vastly different knowledge, of vastly different topics. We situated the course in a community of practice and culture familiar to academic researchers. Given the strong push for academic entrepreneurship on our campus, we also wanted to create an accurate portrayal of these activities as they exist in our regional ecosystem, where there is significantly less access to capital, entrepreneurial talent and start-up business resources than in other parts of the country.

Evaluation data indicate that the course has been successful in meeting these objectives. Participants demonstrated significant gains in self-efficacy related to technology development and business development tasks, supporting our goals of improving not only confidence related to venture development but also offering new perspectives on research and innovation tasks. The results also indicated that enrolling in the course did not increase students' interest in startup activity to a great degree in the near term, suggesting that they were able to think critically about the risks and benefits associated with academic entrepreneurship. It is possible that the candid personal experiences of speakers moderated their ambitions, or they will choose to pursue commercialization activities when the timing is right or they feel better prepared to do so.

Refining our course outcomes over the past seven years was critical given other technology entrepreneurship initiatives on our campus, and research indicating that the rationale for STEE is typically education, but the vetting of real technologies is often the desired outcome (Nelson and Monsen 2014; Phan et al. 2009). Defining outcomes is important at a large research university where prioritizing of STEE-related activities can be complex. For example, institutional metrics (e.g., achieving technology transfer targets) may conflict with academic researcher priorities (e.g., finishing a degree, getting tenure). Therefore, it is important to clearly distinguish between the ‘‘institutional outcomes,” where the unit of analysis is the university, and “individual outcomes,” where the unit is the single academic scientist (Wright et al. 2009, p. 564). There is an opportunity for researchers and administrators to evaluate the influence of STEE through a broader set of measures that include influences on research, education, and institutional culture.

As such, an important aspect of the course is to foster rich discussion around these issues as well as the personal and professional returns of researchers becoming involved in technology commercialization activities. This is particularly important in light of the increasing pressure in academia to promote university startups as metrics of success (Hand et al. 2013a, b; Shane 2012). While there are many potential positive outcomes associated with academic entrepreneurship, scholars have also begun to examine potential losses associated with this movement (Caulfield and Ogbogu 2015; Love 2013; Shane 2012). These can include: focusing on applied research at the expense of basic research; overhyping of scientific and commercial impacts in order to meet public relations and institutional expectations; neglecting teaching and research responsibilities; and the high costs of patent filings and commercialization staff—all of which warrant exploration on an individual and institutional level.

The truth is that it is difficult to pinpoint the combination of policies and factors that will lead to groundbreaking university innovations with commercial potential. From a program perspective, it is unclear to what extent education (e.g., courses) or experiential programs (e.g., NSF I-Corps) can move the needle. From a faculty perspective, it is unclear whether universities should hire certain academics to focus on research, hire others to focus on commercialization, or try to “up the skill and motivate each and every academic to be ambidextrous” (Miller et al. 2018, p. 21). Nonetheless, our experience suggests that providing researchers with more knowledge about the process enables them to make more informed decisions and partake in policy decisions related to academic entrepreneurship. This, in turn, is likely to contribute to bridging the “valley of death” via more informed decision making and more efficient deployment of resources.

Despite the value the course provides to graduate students and faculty, a major challenge continues to be raising awareness of the relevance of STEE to scientific training, and recruiting participants given the prevailing culture and norms in academia. The time demands associated with doctoral programs and research are significant barriers to broader participation. To grow participation, faculty advisors and academic departments must support student involvement in STEE and understand that it complements rather than detracts from research. In our model, we try to account for faculty advisor concerns about time in our course design and promotion. We ensure that the readings and assignments are manageable given the broader responsibilities of participants, and position them as highly relevant to their research and career interests. We offer the course in the evenings to avoid interference with research responsibilities, the tradeoff being encroaching on family responsibilities.

The perception of entrepreneurship as a business function is also a barrier. Therefore, how entrepreneurship is positioned can fundamentally affect the extent of its appeal to both students and faculty. Using a broad and inclusive definition of entrepreneurship can be crucial to reaching many potential entrepreneurs who do not realize the subject is relevant to them or their fields (Hulsey et al. 2006). Our enrollment data suggests that we tend to attract a self-selected population of individuals who have had some prior exposure to commercialization or business through their contacts or own professional experience. Attracting students with no such exposure is considerably more challenging. Greater participation requires that academic departments actively promote participation by communicating that STEE involvement is not detrimental to a students' academic and research progress, and instead better prepares them for both academic and non-academic careers.

7 Conclusion

Universities are encouraging students and faculty members to pursue technology entrepreneurship in order to demonstrate the contributions of academic institutions to communities and the economy. Therefore, it is important for graduate students and faculty to understand the process of translating research into commercial products, regardless of whether or not they are direct participants. The objective of this STEE model is to prepare scientists and engineers to participate in technology translation activities, while at the same time providing a forum for interdisciplinary interaction and professional development. Given the human and financial resources it takes to bring innovation to the market, increased awareness of these complexities and best practices can provide benefits to all stakeholders involved.

Appendix 1: Sample syllabus

ABE/TLI 62600: Life of a Faculty Entrepreneur: Discovery, Development and Translation

Thursdays, 5:30–8:20 pm—3 credits

Instructors

Michael Ladisch	**Nathalie Duval-Couetil**
Distinguished Professor, Agricultural and Biological Engineering & Weldon School of Biomedical Engineering	Professor, Technology Leadership and Innovation
Director, Laboratory of Renewable Resources Engineering	Associate Director, Burton Morgan Center
	Director, Certificate in Entrepreneurship and Innovation

Course description

The course introduces graduate students and faculty to the intellectual, leadership, financial, and management processes for translating research into tangible products. The focus is on university initiated, early-stage commercialization activities. Lectures and reading materials address concepts and resources related to market research, financial analysis, intellectual property policy, commercialization pathways, and entrepreneurship, all of which are pertinent whether graduates choose careers in industry or academia. The course emphasizes:

- Processes through which research is translated from laboratory to product
- Frameworks for analyzing when technologies should be launched and how different pathways may lead to success
- Case studies that illustrate business principles, commercialization strategies, and resources that assist in these efforts

Purpose and objectives

The intent of the course is to complement graduate student research activities and not detract from them in terms of content and time. Students are challenged to think systematically and analytically about processes that move research beyond publications, papers, and patents in order to initiate commercialization. We do not expect that all participants will have a technology that is ready for commercialization, which is often the case in other programs. Rather, our goal is to provide frameworks that will help university entrepreneurs define possible entry points to the commercialization process, and determine their best options prior to getting started. The course objectives are as follows:

1. Expose students to the process of research translation and commercialization
2. Prepare them to think critically about whether they want to participate, how best to participate, what to expect as outcomes, and how to position their research to keep options open
3. Provide a new lens through which they can evaluate their research and frame future proposals
4. Contribute to participants' professional development by providing an understanding of the business context for their research

Course topics

Readings will be assigned by the instructors and will draw from a variety of academic, technical and business journals. Weekly lectures will address a set of 14 factors pertinent to science and technology-based entrepreneurship education. These focus heavily on the development of technology, while also integrating critical thinking related to the business, legal, career, and personal decisions necessary during each stage of commercialization. These factors include:

1. Proof of concept vs. actual prototypes
2. Timing: technology readiness, market readiness, and career readiness
3. Need for research discipline to achieve reproducibility of results and product robustness
4. Disclosures, provisional patents, patents, publications (the need for speed)
5. Freedom to operate analysis
6. Defining pathways: licensing vs. startup
7. Role of networking and entrepreneurial ecosystem
8. Building a business team to move from prototype to product
9. Sources of corporate and project capital vs organic growth
10. Understanding investors
11. Effective communication
12. Managing conflicts of interest
13. Financial and personal costs (and benefits) to founders of new ventures
14. Leadership

Assignments and grading

Assignments guide students, both individually and in teams, in developing a plan for commercialization in an area of technology relevant to their research or interests. Past commercialization projects have been in areas such as instrumentation, molecules, organisms (microorganisms, plants, or animals), catalysts (chemical or biochemical), biomedical devices, mechanical devices, agricultural technology, unmanned aerial vehicles, laboratory instruments, software, big data, and cybersecurity. If a student does not have a topic of their own, they will be assigned to a team.

Grades will be based on reading assignments, participation, two reflection papers, and a project/plan for translating technology from the laboratory to a commercial setting. The final written project and oral presentation will be graded in two parts (each worth 200 points). Projects will be developed in teams of three and in consultation with the instructors. Final oral presentations will be to a panel of experienced experts and entrepreneurs, who will evaluate the project and provide feedback.

Assignments and Grading	Points
Classroom, attendance, participation, and reading assignments	250
2 Reflection Papers—require students to apply the 14 factors and what they have learned through lectures and readings. They should be approximately1200 words excluding citations, tables, and figures	
Reflection 1: Apply what you know of the 14 factors to date to your own research	150
Reflection 2: Apply the 14 factors to an emerging technology to be announced by the instructors	150
Preliminary oral presentation of project idea	50
Special Topic Project	
Oral presentation	200
Written Report—due during finals week	200
Total possible points	1000

Examples of required and supplemental readings/resources

Academic Entrepreneurship

Gould, J. (2015). How to build a better PhD. *Nature News*, *528*(7580), 22.

Loise, V., & Stevens, A. (2010). The Bayh-Dole Act turns 30. *Science Translational Medicine*, *2*(52).

Kolympiris, C., & Klein, P. G. (2017). The effects of academic incubators on university innovation. *Strategic Entrepreneurship Journal*, *11*(2), 145–170.

Kuzubek, J. (2016, October). If billionaires fund your research, don't take public money, *WIRED*.

Lowe, R., & Gonzalez-Brambila, C. (2007). Faculty entrepreneurs and research productivity. *The Journal of Technology Transfer*, *32*(3), 173–194.

Markman, G., Gianiodis, P., & Phan, P. (2008). Full-time faculty or part-time entrepreneurs. *IEEE Transactions on Engineering Management*, 55(1), 29–36.

Owen-Smith, J., & Powell, W. (2002). Standing on shifting terrain: Faculty responses to the transformation of knowledge and its uses in the life sciences. *Science & Technology Studies.*

Renault, C. (2006). Academic capitalism and university incentives for faculty entrepreneurship. *The Journal of Technology Transfer*, *31*(2), 227–239.

Tabuchi, H. (2014, October). Venture capitalists return to backing science start-ups. *New York Times*.

Valdivia, W. (2013). University start-ups: Critical for improving technology transfer. *Center for Technology Innovation at Brookings.* Washington, DC: Brookings Institution.

Wood, M. (2011). A process model of academic entrepreneurship. *Business Horizons*, *54*(2), 153–161.

Science, Technology & Innovation

Dyer, J., Gregersen, H., & Christensen, C. (2009). The innovator's DNA. *Harvard Business Review*.

Hunter-Tilney, L. (2010, September). The music industry's new business model. *Financial Times Magazine*.

Ladisch, M., Ximenes, E., Engelberth, A., & Mosier, N. (2014). *Biological engineering and the emerging cellulose ethanol industry.* Chemical Engineering Progress, 110(11), 59–62.

Mims, C. (2017, November). Laws of innovation everyone should heed. *Wall Street Journal*.

Naik, G. (2013, January). Storing digital data in DNA. *Wall Street Journal*.

Rangan, V. (1994). New product commercialization: Common mistakes. Harvard Business School Case #594127.

Schechner, S., MacMillan, D. & Lin, L. (2018, January). U.S. and Chinese companies race to dominate AI. *Wall Street Journal.*

Stuart, T., & Anderson, C. (2015). 3D Robotics: Disrupting the drone market. *California Management Review*, *57*(2), 91–112.

Thomke, S., & Nimgade, A. (1998). Innovation at 3 m corporation (a). Harvard Business School Case #699012

Thomke, S., and B. Feinberg. (2012). Design thinking and innovation at Apple (1997–2002), Harvard Business School Case #609066.

Wang, S. (2013, January). The quest to create a bionic eye gets clearer. *Wall Street Journal*.

Winkler, R. (2013, January). Apple draws the short quarter. *Wall Street Journal*.

Zwilling, M. (2012, May). 6 reasons why working prototypes attract investors. *Fortune*.

Leadership Q & A, Leading a Business from Startup to Scale-up (Genomatica), *CEP Magazine*, 112(11), 24–25 (2016).

Business Startup Fundamentals

Blair, E., & Marcum, T. (2015). Heed our advice: Exploring how professionals guide small business owners in start-up entity choice. *Journal of Small Business Management*, 53(1), 249–265.

Bruns, W. (2004, September). Introduction to Financial Ratios and Financial Statement Analysis, Harvard Business School Case #193029.

Carryer, B. (2017). Startup Briefs: The Ultimate No-Holds-Barred Guide to Start a Startup. *Self Published*.

Chamberlin, J. (2017, December). The 3-min pitch. *American Psychological Association, Monitor on Psychology*, https://www.apa.org/monitor/2017/12/three-minute-pitch.

Chesbrough, H. (2007). Business model innovation: It's not just about technology anymore. *Strategy & Leadership*, 35(6), 12–17.

Elsbach, K. (2003, September). How to pitch a brilliant idea, Kimberly Elsbach. *Harvard Business Review*.

Gilbert, C., & Eyring, M. (2010). Beating the odds when you launch a new venture. *Harvard Business Review*, 88(5), 92–98.

Goleman, D. (2000). Leadership that gets results. *Harvard Business Review*, *78*(2), 4–17.

Hamermesh, R., Marshall, P., & Pirmohamed, T. (2002). Note on business model analysis for the entrepreneur. Harvard Business School Case #802048.

Kerr, W. and Nanda, R. (2011, March). Financing New Ventures. Harvard Business School, Case #811093.

Marcum, T. & Blair, E. (2011). Entrepreneurial decisions and legal issues in early venture stages: Advice that shouldn't be ignored. *Business Horizons*, *54*(2), 143–152.

Zider, B. (1998). How venture capital works. *Harvard Business Review*, *76*(6), 131–139.

Roberts, M. & Stevenson, H., (2005). Deal structure and deal terms, Harvard Business School Case #806085.

Rosenberg, T. (2009). A note on valuation for venture capital. Richard Ivey School of Business Case.

Sahlman, W. (1997). How to write a great business plan. *Harvard Business Review*, *75*(4), 98–108.

Sahlman, W, & Willis, R. (2003, revised 2009). The Basic Venture Capital Formula. Harvard Business School Case #804042.

Spradlin, D. (2012, September). Are you solving the right problem? *Harvard Business Review*.

Stancill, J. (1986, May). How much money does your new venture need? Harvard Business School Case #86314.

Thomke, S., & Feinberg, B. (2009). Design thinking and innovation at Apple. Harvard Business School Case #609066.

Videos

Steve Jobs interviewed just before returning to Apple (1996). It's not about the software—but innovation and business model. Sept 18, 2011. http://www.youtube.com/watch?v=SaJp66ArJVI

Kawaski, G., The top 10 mistakes of entrepreneurs, (2013). http://www.youtube.com/watch?v=HHjgK6p4nrw

Rose, D. Ted Talk: How to pitch to a VC. https://www.ted.com/talks/david_s_rose_on_pitching_to_vcs

Appendix 2

See Table 7.

Table 7 Pre- and post-program comparisons for venturing and technology self-efficacy scales

	Mean (SD)		t	d^+
	Pre	Post		
Venturing self-efficacy				
Know the steps needed to place a financial value on a new business venture	3.58 (2.15)	7.59 (1.74)	18.31***	1.65
Pick the right marketing approach for the introduction of a new service	4.54 (2.52)	7.87 (1.79)	14.68***	1.35
Work with a supplier to get better prices to help a venture become successful	4.50 (2.56)	7.44 (2.18)	14.76***	1.34
Estimate accurately the costs of running a new project	4.98 (2.70)	7.47 (2.03)	10.93***	1.00
Recognize when an idea is good enough to support a major business venture	5.69 (2.51)	8.39 (1.82)	11.97***	1.09
Recruit the right employees for a new project or venture	5.52 (2.67)	8.25 (1.95)	12.30***	1.14
Convince a customer or client to try a new product for the first time	5.92 (2.80)	8.29 (1.93)	10.56***	0.98
Write a clear and complete business plan	4.73 (2.87)	7.79 (2.17)	12.16***	1.11
Technical-functional self-efficacy				
Convert a useful scientific advance into a practical application	5.94 (2.76)	8.59 (1.83)	10.50***	0.97
Develop your own original hypothesis and a research plan to test it	7.67 (2.60)	9.36 (1.49)	7.85***	0.75
Grasp the concept and limits of a technology well enough to see the best ways to use it	7.16 (2.49)	9.14 (1.49)	10.40***	1.02
Design and build something new that performs very close to your design specifications	6.84 (2.51)	8.84 (1.71)	9.88***	0.92
Lead a technical team developing a new product to a successful result	6.43 (2.60)	8.83 (1.64)	12.16***	1.17
Understand exactly what is new and important in a groundbreaking theoretical article	7.30 (2.38)	8.94 (1.64)	8.45***	0.79
Translate user needs into requirements for a design so well that users will like the outcome	6.93 (2.52)	8.79 (1.69)	8.60***	0.80

$^+$Effect sizes (d) were calculated using the Morris and DeShon (2002) equation

***< .001

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