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Teaching Entrepreneurship with Societal Impact to Engineering Students

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Teaching Impactful Entrepreneurship to Engineering Students

Abstract

Engineering education endeavors to impart the skills students need to solve technological challenges, while entrepreneurship education endeavors to impart the skills needed to solve the commercialization challenges. However, society benefits only when both sets of challenges are solved. Students are aware of crises affecting society, such as healthcare disparity and clean energy, but few have experience combining engineering and entrepreneurship to address them. This paper presents a one-semester undergraduate college course that, building on three pillars, teaches undergraduate students how to pursue societally significant opportunities. The first pillar is the distinction between tacit and codified knowledge in opportunity recognition. The second pillar is metacognition to build students' self-efficacy in the requisite applied and social sciences. The third pillar is the protocol of the federal Small Business Innovation Research program ("America's Seed Fund"). The multidisciplinary course emphasizes strategic partnerships, navigating funding protocols, and grantsmanship - skills of value in startup, corporate, academic, and public service settings.

Introduction: Tacit Knowledge and Societal Significance

An initial activity in both entrepreneurship education and practice is opportunity discovery. In the case of entrepreneurship education, students search for a business opportunity that serves as the context for subsequent course activities (Neck, Neck, & Murray, 2019; Zacharakis, Bygrave,

& Corbett, 2017). Because industry experience correlates with successful opportunity discovery, educators also recommend that students build upon tacit knowledge they obtained from experience (Azoulay, Jones, Kim, & Miranda, 2020; Oe & Mitsuhashi, 2013). However, this advice leads to students pursuing simple opportunities because students tend to have limited industry experience. When considering opportunities for innovations with societal significance, such as healthcare, energy and the environment, students are at a disadvantage. Students are aware of societally important issues but few have tacit knowledge with which to recognize opportunities for technological solutions that can scale, or distinguish good market opportunities from bad ones (Bandera, 2021).

This paper presents a framework for teaching students how to apply their engineering skills to solve problems with societal significance. Instead of relying on tacit knowledge to guide opportunity discovery, it uses the systematic search of solicitations from by federal agencies tasked with addressing such problems, and metacognition exercises to help students build self-efficacy. We then present a course "ENT330 Entrepreneurial Strategy" that implements this framework in an undergraduate entrepreneurship education program offered by the school of business in a polytechnic research university. ENTR330 students search for codified opportunities with societal significance for technological innovations, including innovations students developed in other engineering courses, and formulate sustainable strategies for the pursuit these opportunities.

Discovering Codified Opportunities

Smith, Matthews, and Schenkel (2009) characterize an entrepreneurial opportunity as well-documented (codified) or undocumented (tacit). They then present an "individual–opportunity nexus" with two dimensions: the entrepreneur's prior knowledge of an opportunity and the tacit nature of the opportunity (Figure 1). The nexus defines a 2-D map of opportunity discovery strategies, the top left being the strategy most often used in entrepreneurship education: using prior knowledge to find tacit opportunities.

		Attribute of Entrepreneur's Knowledge	
		Prior Knowledge	No Prior Knowledge
Attribute of Opportunity	Tacit	Discovery	Unworkable
	Codified	Focused Search	Systematic Search

Figure 1. The Individual–Opportunity Nexus

(adapted from Smith, Matthews, and Schenkel, 2009)

Just one workable strategy in the individual–opportunity nexus is available to encourage students to "aim higher" and address opportunities for which the student lacks prior experience: searching the documentation available on codified opportunities. One impediment for this strategy is that few educators are familiar with standardized data for such opportunities or the strategies and protocols for their pursuit. Fortunately, these codified resources now exist in the public domain, and they include rubrics for the evaluation of innovations and business models, and definitions for societal significance.

SBIR Resources for the Entrepreneurship Student

The course uses the resources of the federal Small Business Innovation Research (SBIR) program, euphemistically known as "America's Seed Fund" (United States Small Business Administration, 2021). Even though more than one third of the US technology ventures participating in the SBIR program employ three or less people, the program accommodates ventures with up to 500 employees. Consequently, working knowledge of the SBIR program is relevant skill for students seeking to start a technology venture or seeking to join the small business job market to commercialize technological innovation.

Enacted by Congress in 1982, the Small Business Innovation Research (SBIR) program is the largest innovation commercialization program in the US (Audretsch, 2003). Known as "America's Seed Fund" (United States Small Business Administration, 2021), the SBIR program funds for-profit small ventures to develop and commercialize technological innovation aligned with the missions of the federal agencies that administer the program, namely the National Science Foundation, the National Aeronautics and Space Administration, the Environmental Protection Agency, and the Departments of Agriculture, Commerce, Defense (DOD), Education, Energy, Health and Human Services (HHS), Homeland Security, and Transportation. Many of today's important innovative companies, such as Biogen and Qualcomm, were initially financed by the SBIR program.

The projects funded by the SBIR program reflect societal significance of the missions of the aforementioned participating agencies. Every year, each participating federal agency compiles,

ranks, down selects, and publishes a list of desired STEM-based innovations that are aligned with its societally significant mission but which are not commercially available. Each agency also publishes instructions on how to apply for SBIR funding, how applications are evaluated, abstracts of previous awards (the proposals themselves are confidential), and award statistics.

The number of solicited innovations, called "topics" in SBIR parlance, has increased from 842 in 2011 to over two thousand in 2018 (United States Small Business Administration, 2021). Each topic includes a description of the desired innovation and its significance, and the contact information for the government official advocating the topic. The SBIR program only invests in for-profit ventures whose innovations and business plans support at least one topic. The SBIR program structures funding in two phases: Phase I is typically for concept feasibility (usually a 12 month $100K award), and Phase II is for developing and testing a working prototype (usually a 24 month $1MM award).

Congress monitors the return on its investment in the SBIR program, and uses the commercial success of the ventures funded by the program as a key performance indicator (KPI) (National Academies of Sciences, Engineering, & Medicine, 2014, 2015a, 2015b, 2015c, 2016a, 2016b). Unlike academic research proposals, a competitive proposal for SBIR funding has to present a convincing commercialization strategy and customer engagement activities such as requirements verification and pilot testing. Competitive SBIR proposals are thus inherently multidisciplinary, combining applied and social sciences.

In order to advance the above KPI, federal agencies participating in the SBIR program conduct outreach to educate entrepreneurs about the program and how to use it successfully. The outreach includes workshops where practitioners and SBIR officials meet, online tutorials on the administrative and scientific requirements that participating ventures must meet, and showcases of commercial success stories. To further advance the KPI, federal agencies also host "matchmaker" programs that pair SBIR awardees with corporations seeking acquisitions or meeting quotas for outsourcing to small businesses. While never intended to be used for undergraduate courses, these SBIR outreach resources nevertheless serve as free and up-to-date teaching resources valuable in undergraduate settings.

Self-Efficacy though Metacognition

Students' limited tacit knowledge in scalable societally significant entrepreneurship limits their self-efficacy at the start of the course and in some cases manifests as a defeatist attitudes such as, "I know about these big problems, but what can I do about them?" A pedagogical challenge is to prevent such attitudes from getting in the way of learning from the course and acting entrepreneurially in the future. We cannot endow students in one semester with a career's worth of tacit knowledge, but through metacognitive exercises, students can come to appreciate that codified opportunities and protocols compensate for missing tacit knowledge to some degree.

Entrepreneurship education researchers have found that metacognition correlates with self-efficacy (Kim & Lee, 2018; Mitchell, Gustavsson, Smith, Davidsson, & Mitchell, 2005; Ustav & Venesaar, 2018). Bloom's taxonomy of educational objectives revised by Krathwohl (2002)

explicitly addresses metacognition. Specifically, the revised taxonomy consists of two dimensions: the original six cognitive processes (Remember, Understand, Apply, Analyze, Evaluate, and Create) crossed with four knowledge processes: Factual, Conceptual, Procedural, and Metacognitive. We can thus use the last knowledge process to help students build self-efficacy with SBIR protocols, and thereby with engineering for societal significance.

ENTR330 Syllabus and Key Activities

ENTR330 uses the lists of SBIR topics as a codified resource. Each topic represents an entrepreneurial opportunity that is societally significant in the sense that the participating agencies are societally significant. ENTR330 also uses the SBIR instructions, rubric, and outreach documentation of each agency as a codified resources to guide students through the process of articulating and budgeting a response to a topic. Students with existing innovations, such as capstone, hackathon, or studio projects, are encouraged in the course to pursue societally significant applications of their innovations.

ENT330 consists of three modules that are similar to those of a traditional entrepreneurship course: opportunity discovery, risk reduction, and strategy evaluation. However, the corresponding activities (Table 1, left) are conducted in the context of the SBIR program (Table 1, right). Students' major work product is an SBIR proposal. Students are not required to submit their proposals, as this has legal prerequisites including the formation and registration of a for-profit entity, and post-award requirements including the availability of students to conduct the funded work, to which students might not be able to commit.

Table 1. Alignment of ENT330 syllabus with SBIR protocols

Module 1: Opportunity Discovery

Course Activities	SBIR Protocol
Opportunity Search	Topics / Solicitations
Value Proposition	Significance, Innovation, Differentiation

Module 2: Risk Reduction

Team Formation	Key Personnel, Collaborators
Prototyping Strategy	Work Plan, Beta Testers, Subcontractors, Endorsers
Finance	Plans for Future Funding, Grants versus Contracts

Module 3: Strategy Evaluation

Regulatory Considerations	Human Subjects Protection, Export Control, Intellectual Property Protection and Licensing
Accounting	SBIR Budget, Direct and Indirect Costs
Peer Review	Evaluation Criteria

In some respects, it is easier to write an SBIR proposal than business plan (a common assignment in traditional entrepreneurship courses). Both require a description of the offering, target market, value proposition, and milestones leading to the deployment of a minimum viable product or service. However, federal agencies explain in detail the rubric with which SBIR proposals are evaluated; this guides the student's writing and makes grading less subjective than grading a business plan. Moreover, business plan financials are projections with notoriously questionable accuracy, whereas proposal financials describe how the award funds will be spent to achieve the stated milestones and are easier to quantify.

ENTR330 students maintain an online journal in which they enter their responses to metacognitive questions that use the SBIR program as a "hard scaffolding" (An & Cao, 2014).

The metacognitive questions are designed to guide the student to conclude that s/he can use the SBIR program to manage the risk and uncertainty of societal significance (and should, as that is precisely the program's purpose). These questions, along with the class assignments that lead to the development of self-efficacy and a complete SBIR Phase I proposal, are presented in Table 2.

Table 2. Bloom's revised taxonomy. Each cell includes an ENTR330 assignment designed to strengthen the corresponding cognitive process and knowledge.

Cognitive Process Dimension	Knowledge Dimension: Factual The basic elements a student must know to be acquainted with a discipline or solve problems in it.	Conceptual The interrelationships among the basic elements within a larger structure that enable them to function together.	Procedural How to do something, criteria for using skills, algorithms, techniques, and methods.	Metacognitive Knowledge of cognition in general; awareness and knowledge of one's own cognition.
Remember	Where can you find more information on the SBIR program?	How do grants differ from equity investments?	Recall how to register a venture for SBIR funding.	What motivates you to bring innovation to market? What demotivates you? Do you think you are ready to make a societally significant impact with it?
Understand	What is the goal of the SBIR program? Who funds it?	Is a startup a commercial success upon receiving SBIR support? Explain.	Does a grant mean the venture cannot pivot?	Do you believe others think you might qualify for the SBIR program? Why or why not?
Apply	Pick a federal agency. Find its list of small business opportunities.	Pick a patent owned by your university; is there a funding solicitation for it?	Find a solicitation for your innovation. Justify your selection.	List ways your attempt to bring your innovation to market might fail. How could you use the SBIR program to recover from each failure?
Analyze	How do agency expectations differ between Phase I & II?	How might a startup differentiate between two funding opportunities?	What is your value proposition to the funding agency?	How would you teach this course? Describe the kind(s) of students you would like in your class.
Evaluate	How do agency expectations differ between agencies?	How might agencies improve their selection of awardees?	With whom might you collaborate and why?	What would an agency believe you lack (is your weakest point), and how might you get (fix) it?
Create	Generate a log of daily activities.	How would a review board judge my idea and approach?	Write a complete Phase I proposal.	How might you apply what you have learned in this course in your job?

Module 1: Opportunity Discovery

The opportunity discovery module of ENT330 begins with each student surveying the SBIR topics in areas that interest her/him, or which are aligned with her/his prior innovation. The search for topics is hierarchical, beginning with surveying missions of the twelve agencies participating in the SBIR program (bold in Figure 2). Students then investigate which of the components of the agencies are most relevant to her/his interests or innovation. ENTR330 students conduct opportunity discovery individually. Once a student finds a relevant topic, s/he presents it to the class in the form of a business model canvas (Osterwalder & Pigneur, 2010). Students can then form teams around business models that are appealing and convincing.

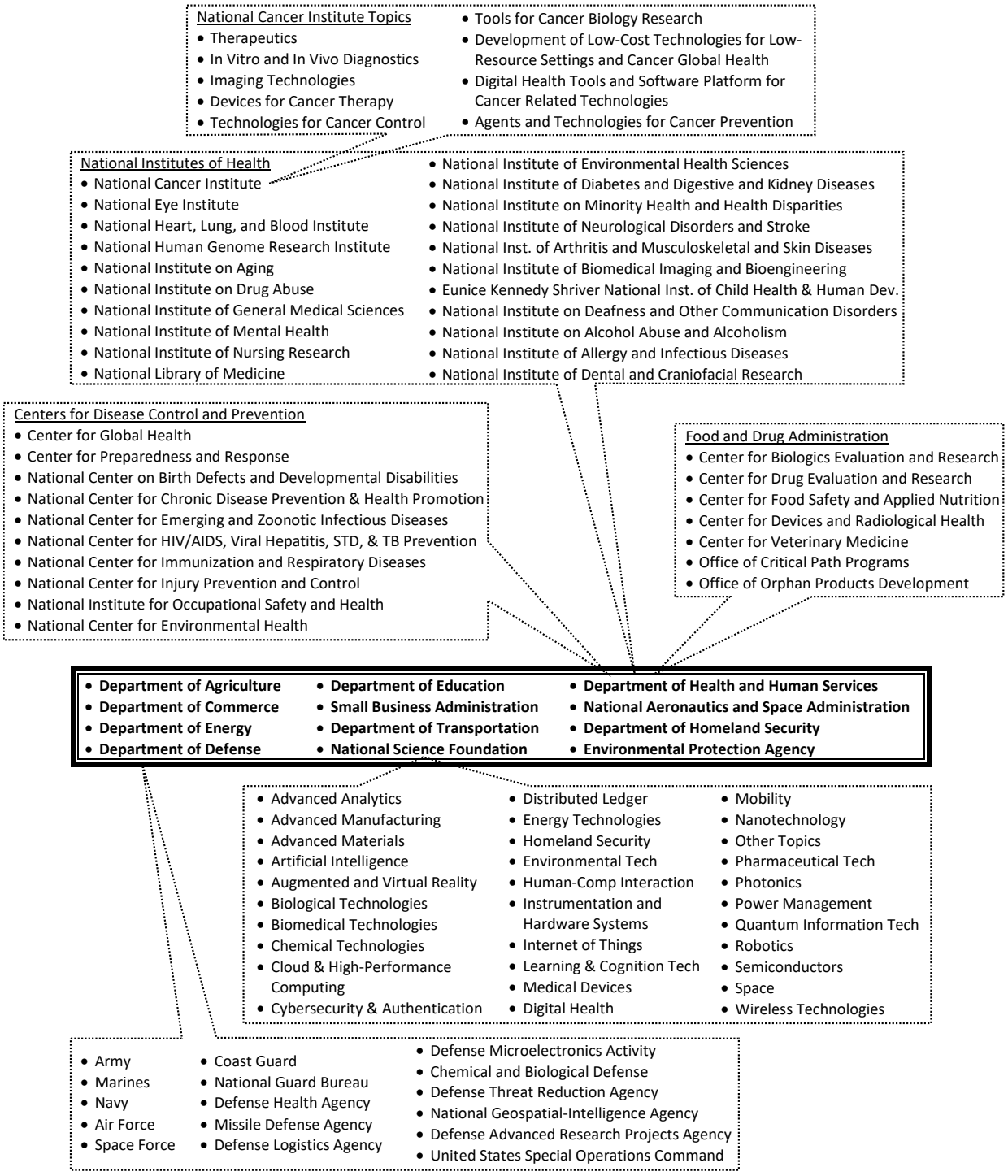

Figure 2. Subset of hierarchy of codified SBIR opportunities (hierarchy root in bold)

Figure 2 illustrates the three top-level components of the Department of Health and Human Services (DHHS), namely the National Institutes of Health, the Centers for Disease Control and Prevention, and the Food and Drug Administration. These three components consist of 37 institutes and centers, one of which is the National Cancer Institute (NCI), which supports nine broad topics. In 2021, NCI alone made 247 SBIR awards totaling over $155.9M to small for-profit ventures developing innovations that address these nine topics (source: NIH Research Portfolio Online Reporting Tools - Expenditures and Results module, filter: R41-R44 FY21 awards, https://report.nih.gov/).

Figure 2 also illustrates the top-level components of the Department of Defense (DOD). DOD has the largest SBIR budget of all agencies, awarding over $1.8B in FY2020 (source: https://www.sbir.gov/analytics-dashboard). DOD has 16 top level components, indicative of an opportunity hierarchy that is more complex than that of DHHS. Figure 2 also illustrates the top-level components of the National Science Foundation's SBIR program. NSF "invented" the SBIR program, and has the broadest topics of all participating agencies.

Finding a topic that matches the student's innovation or interest has three pedagogical implications. First, it is a real-world validation of the innovation's societal significance. The second implication is strategic. At times, entrepreneurs will not find a topic that is perfectly aligned with their strategy. For example, a topic may require functionality that is not part of the innovation, or require the entrepreneur to enter a market that is unrelated to the one s/he was initially considering. In such cases, before writing an SBIR proposal, the entrepreneur must determine if an award will commit the venture to a strategic direction that the entrepreneur does

not desire, such as serving a market that makes the entrepreneur uncomfortable. The ENT330 student is instructed to take similar considerations into account when evaluating topics.

Third, this activity presents students with case studies of other startups pursuing similar opportunities. It also presents to students an appealing context in which to learn about the risks of traversing the "Valley of Death" which innovations much cross in order to achieve commercialization (Wessner, 2005). Students chronologically research case studies using the following steps: (1) identify an SBIR topic of interest announced some prior year, (2) analyze the abstract of the winning innovation, and (3) research the execution and growth (or failure) of the winning venture.

Module 2: Opportunity De-Risking

Each student team formed in Module 1 is responsible for writing a SBIR Phase I proposal for the selected topic and business model. While the detailed structure of an SBIR proposal varies among different agencies, all SBIR proposals include a description of the innovation and its distinguishing features, a description of the innovation's significance, and a work plan to de-risk the innovation with the budget and schedule constraints of the agency's Phase I awards.

ENT330 requires students to design stakeholder engagement activities such as user focus groups and beta testing, and include any necessary subcontracts to stakeholders in the budget, and draft stakeholder letters of collaboration in their work plan. The design of stakeholder engagement is itself a multidisciplinary de-risking activity. User focus groups often require a trusted facilitator

(another important type of stakeholder) to recruit participants, such as an advocacy organization for the problem addressed by the innovation; ENT330 requires that students identify these facilitators and discuss with them a plan to engage users that falls within the Phase I budget and time constraints. As associated topic covered by ENT330 is human subject protection protocols.

Module 3: Strategy Evaluation

As students prepare the different sections of their proposals, they learn the criteria with which agencies evaluate those sections, and each student is required to evaluate the proposal of a peer following this rubric. A Phase I proposal with a convincing de-risking strategy will rank more favorably than a proposal with a higher value innovation but a poorly described de-risking strategy. The evaluation criteria are as follows:

1. Innovativeness of value proposition. Why will it succeed where others have failed?
2. Societal significance of value proposition. Does your innovation help a vulnerable population?
3. Fit between the business concept and an explicit solicitation (topic) or the mission of the target agency. One-on-one discussions with program officers are encouraged.
4. Feasibility of de-risking strategy. Must be within Phase I time and budget constraints. Is the combined expertise of the student team, partner organization, consultants, and/or subcontractors sufficient to execute the strategy?
5. Budget. Are direct and indirect expenses accounted for and justified? Does the budget comply with statutory and agency-specific limits?

6. Commercialization strategy. Is the target market the federal agency (e.g., DOD), or is the federal agency subsidizing the development of innovation for commercial markets?
7. Boilerplate material: resumes, draft teaming agreements, protection of human subjects and intellectual property (if applicable). Students also have to draft the letters they would hope to obtain from collaborators and endorsers.

Discussion

ENTR330 has been offered three times with a total enrollment of 59 students from different disciplines (35 business, 11 engineering, 7 computer science, 2 liberal arts, and 4 unmatriculated) producing 22 SBIR Phase I proposals (9 NIH, 3 NSF, 3 EPA, 2 CDC, 2 DOD, 2 DOT, and one DOEd). Table 3 compares ENTR330 and traditional entrepreneurship courses (Sirelkhatim & Gangi, 2015). ENTR330 focuses on STEM-based innovation with societal significance. It also serves university innovation programs such as I-Corps which prepares faculty-student teams for SBIR funding (Huang-Saad, Fay, & Sheridan, 2017). ENT330 students learn not just about company formation, but also how to do business with the government. SBIR topics, however, by definition do not lend themselves to easy "side hustles."

Table 3. Major differences between ENT330 and traditional entrepreneurship courses

	ENT330	**Traditional Entrepreneurship Course**
Domain	STEM-based innovation, societal significance	General, within students' prior experience
Integration w. other student activities	Capstone projects, I-Corps, sponsored research	Capstone projects
Work products	SBIR Phase I proposal: value proposition, work plan, budget, objective rubric	Business plan: value proposition, work plan, financial projection, subjective rubric
Value beyond graduation	STEM entrepreneurship skills, demanding opportunity, intrapreneurship, tech transfer	General entrepreneurship skills, side hustles
Business protocols	New venture formation, government contractor	New venture formation

Conclusion

This paper describes an undergraduate university entrepreneurship course on the commercialization of technological innovation with societal significance. What began as an attempt to help entrepreneurship students "aim higher" has evolved into a curriculum that involves students from all majors, federal program officers (as guest lecturers), founders of regional startups (as students and also guest lecturers), and university researchers and administration. Students refine multidisciplinary skills including technological subject matter expertise, stakeholder engagement, strategic planning, regulatory compliance, and budgeting. Metacognitive exercises encourage students to reinforce tacit knowledge with SBIR protocols, while the experiential nature of the course promote students' ability to discover codified opportunities. These skills are of value not only to entrepreneurship, but also to intrapreneurship (Maier & Zenovia, 2011) and careers that involve the management of innovation in the corporate, public, and academic settings.

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