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A Theoretical Framework to Synthesize Entrepreneurial Thinking in STEM Teaching and Learning

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Abstract

The advent of global challenges and unprecedented levels of human activity have placed a premium on science and technology to help address the needs of an evolving global population. STEM (Science, Technology, Engineering and Math) educated individuals have the potential to meet these needs; however, teaching and learning in STEM often ends with the development of an abstract theory or model. Traditionally, higher education focuses on theory construction. The commercialization potential of advances in science and technology is often limited by the isolation of science and technology from markets. In this paper, a teaching and learning framework for the integration of entrepreneurial attitudes and skills in higher education STEM programs is proposed. The framework consists of three interrelated elements; i) Idea and Market Analysis, ii) Product/Service Development and iii) Commercialization. Each element is elaborated and discussed with respect to the theory of Experiential Learning, Self-Efficacy and the Triple Helix Model.

Keywords

Higher Education, Entrepreneurship, Stempreneurship, Technology and Innovation, Teaching and Learning, Lean Start-Up, Triple Helix Model, STEM Education, ABET

1. Introduction

1.1. Need for STEM in 21st Century

The change and complexity in global economy creates an environment where var-

ious transnational problems (for example, climate change; building a flexible and secure power grid; creating new biotechnology and pharmaceutical products; and establishing safe and secure global information and communication technology (ICT) infrastructure) cannot be resolved without professionals skilled in different domains and fields (Duval-Couetil, 2013). It has been the case that universities and related research institutions have been the main areas where new knowledge and skills have been produced, and the main locations where new products and services have been invented. However, universities have been inefficient in transferring knowledge from the laboratory to the markets and making significant positive changes in people's lives (Kruger & Steyn, 2019).

Knowledge, skills and characteristics, that constitute the main core of educational programs and courses of science, technology, engineering and mathematics (STEM) disciplines, have been focusing on the development of graduates, who are skilled in advanced analysis and careful reasoning, and are able to think abstractly and creatively. However, the main focus of educational programs in STEM areas have been on developing skills that are required to carryout professional practice (Deveci & Seikkula-Leino, 2023). Because of this main emphasis, the practices of economy, regulatory frameworks, and marketing have been largely overlooked in university education. This has made many promising discoveries to remain in the laboratories of universities (Kruger & Steyn, 2019; Markman et al., 2005).

1.2. Innovation Gap and Valley of Death

The "valley of death" has been used to describe the gap between academic research (which is primarily government sponsored) and commercial research and practice (which is sponsored by the private sector, primarily through venture capital) (Kruger & Steyn, 2019; Markman et al., 2005). Academic research helps in creating the main ideas and concepts of a theory, and academic researchers have the skills to validate their ideas. However, there is limited academic research funding to support the creation of fully functioning products that are ready to enter the markets and help realize the researcher's ideas (unit economics and customer adoption, for example).

Later-stage private investors tend to be more risk tolerant and therefore more inclined to invest in science and technology. On the other hand, early-stage private investors, who are more risk averse, tend to fund things such as business plans and management teams. Thus, fundamental research is often not supported by private financing. One of the few ways to finance research in academia is through public funding. As researchers are judged by their ability to publish in academic journals, the commercialization of academic discoveries is often overlooked. As a result, public funding of research often does not lead to the development of infrastructure, products, or services that are commercially available to the public (Etzkowitz & Leydesdorff, 2000; Markman et al., 2005).

A "Valley of Death" exists in the commercialization of academic research between technology and product development and market validation. It has been said that the main reasons for the failure to commercialize academic research are 1) the presence of high technology and low market research, 2) high uncertainty and risk in the commercialization process, and 3) a lack of entrepreneurial skills (Etzkowitz & Leydesdorff, 2000).

There is potential for universities to commercialization academic research, new product development, and technology transfer. University research offices could adopt and evolve practices and business models from industry to achieve success (Etzkowitz & Leydesdorff, 2000).

This paper provides a pedagogical approach to the institutional split in higher education described above. Specifically, the paper:

1) Analyzes the intellectual stream of the entrepreneur in the context of the practitioners of the artistic and technical professions.

2) Presents the STEMpreneurship Framework and method, structure and articulate steps in an engineer's education and career.

3) Proposes administrative and operational policies that encourage interdisciplinary collaboration.

4) Integrates cross-disciplinary perspectives in the assessment of frame/work and determines feasibility from the viewpoint of a practitioner.

2. Theoretical Foundation and Review of the Literature

2.1. Review of Related Works and Methods of Analysis

To develop the three-tier Integration Model we perused research publications in the areas of STEM education and university spinoffs, and models and frameworks in technology and innovation. We took a broad approach in the search by using various combinations of the key words "engineering education", "entrepreneurship education", "engineering innovation", "STEM education and entrepreneurship", and "triple helix model" (Graham, 2018). The relationships among the three curriculum tiers, their theoretical foundations, learning activities, and expected student outcomes are summarized in Table 1.

Table 1. Relationships between learning theories and curriculum tiers.

Curriculum Tier	Core Theoretical Model	Primary Learning Activities	Student Outcome Assessment
Tier 1: Need Discovery	Experiential Learning (Kolb, 1984)	Field observation, stakeholder interviews, user persona mapping	Problem identification skill, empathetic design mindset
Tier 2: Co-Creation	Self-Efficacy Theory (Bandura, 1997)	Functional prototyping, user testing, design iteration	Technical confidence, prototyping skill, adaptability
Tier 3: Translation	Triple Helix Model (Etzkowitz & Leydesdorff, 2000)	Business model formulation, mock IP filing, pitch presentations	Commercialization awareness, technology transfer competence

2.2. Bandura's Self Efficacy Theory

Students from technical and engineering disciplines typically have low business and entrepreneurial self-efficacy. Duval-Couetil et al. (2012) used the term "mismatch" to describe this disparity between the student's technical self-efficacy and their business and entrepreneurial self-efficacy. It is important to address the business and entrepreneurial self-efficacy of students from technical and engineering disciplines to help develop their entrepreneurial mindset.

This creates individuals with a tech background who are uncomfortable discussing aspects of business involving intellectual property, raising capital, and marketing (Duval-Couetil, 2013). With the use of progressive stage structuring (typically found in the Performing Arts) to advance entrepreneurial self-efficacy, this framework would provide the entrepreneurs with the necessary business skills through varied experiences (Bandura, 1997).

2.3. The Triple Helix Model and Academic Technology Transfer

The Rise of STEMpreneurship is associated with the development of the Triple Helix Model of University-Industry-Government relations (Etzkowitz & Leydesdorff, 2000). Essentially, University technology transfer offices are charged with the responsibility of helping to facilitate the commercialization of research within their institutions, mainly through collaborative efforts with industry and government.

Classical models of the Triple Helix show universities patenting and licensing inventions made by faculty members through the establishment of TTOs (Markman et al., 2005). While TTOs continue to play a pivotal role in technology transfer, they suffer from a number of constraints. For instance, TTOs incur significant costs in time and money for patenting processes. These costs may be recovered only if there is eventual interest in the market for the product. Additionally, there is a lack of information between TTOs and faculty members, and between TTOs and the end users of the technology. Finally, universities and academic research laboratories often have difficulties with the commercialization of the research findings. For instance, academic researchers may have little or no understanding of the commercial potential of their discoveries.

Integrating student-faculty partnerships within STEM entrepreneurship student-faculty partnerships to advance technology transfer processes and reduce administrative costs. Customer discovery processes promote technology transfer. Models such as the NSF I-Corps and related programs provide an example of how the integration of entrepreneurship education in higher learning can positively impact the technology transfer processes.

Progressive entrepreneurial modules will be directly incorporated into STEM courses. The goal is to provide all students at all academic levels with exposure to entrepreneurial activities and help integrate the STEM disciplines with market considerations. This approach is facilitated through team efforts of collaborating faculty.

3. The Three-Tier STEMpreneurship Framework

The framework organizes entrepreneurial knowledge and skills to create a progressive pathway towards its practical application.

The Three-Tier Stempreneurship Framework

The pathway is organized into three tiers (levels)—beginning with identifying a business opportunity and advancing to validation and ultimately the commercialization of the business opportunity.

3.1. Tier 1 Pathway to Entrepreneurship

The goal is to shift the entrepreneurial focus from opportunity identification to opportunity creation. This involves moving beyond the traditional pedagogy whereby students at the beginning level are guided to learn how to define and solve business problems.

Integrate Into Existing Courses: Undergraduate design, STEM, and/or engineering and computer science courses.

Breakdown of Module

Week 1: Explored the difference between scientific curiosity and market demand and provides examples on integrating humans in the design process.

Week 2: Learned how to identify and list stakeholders within the targeted technological domain and how to construct an ecosystem map.

Week 3: Reviewed how to effectively conduct customer interviews. Also covered how to determine the true pain or need of a customer by interpreting and analyzing customer feedback (Fitzpatrick, 2019).

Week 4: Learned how to evaluate the size of the market opportunity and how to estimate the Total Addressable Market (TAM), Served/Available Market (SAM), and the Target Market (SOM).

Week 5: Learned how to analyze the competition and how to identify and understand opportunities for technological substitution.

Week 6: Learned how to develop an opportunity pitch and the process for evaluating opportunities.

3.2. Tier 2: Prototyping & Technical Validation (Applied)

3.2.1. Pedagogical Focus and Objectives

Tier 2 leverages lean startup philosophy to associate prototyping with the Build-Measure-Learn cycle. This allows students to build lower-functioning prototypes to evaluate a product or service idea rather than honing a prototype over several weeks to align with a prescribed set of lab requirements (Ries, 2011).

Target Audience: Juniors (3rd year undergraduates) and senior (early 4th year) students.

Key Skills: Prototyping, lab validation, price to performance trade offs, user validation testing, and goal and milestone articulation.

Potential Learning Environment: Engineering design projects, software engineering and other computing projects, and lab science.

3.2.2. Modular Curriculum Breakdown (8 Week Course)

[FORUSE HYPOTHESES]
|
▼
[BUILD A MINIMUM VIABLE PROTOTYPE]
|
▼
[DEPLOY AND TEST IN THE FIELD]
|
▼
[MEASURE AND ITERATE]
|
◂[FORUSE HYPOTHESES]

Weeks 1-2: Defining critical product/service ideas and associated market assumptions (critical assumption testing) and defining a minimum viable product.

Weeks 3-4: Designing and fabricating a minimum alpha/functional prototype, considering trade-offs of price, time and fidelity.

Weeks 5-6: Planning and conducting tests to evaluate product/service idea and user interaction and integration.

Weeks 7-8: Analyzing and evaluating user feedback and integration in engineering design specifications and product/service ideas.

3.2.3. ABET Outcome Alignment

ABET Outcome	Traditional Interpretation	Tier 2 STEMpreneurship Alignment
Outcome 1: Identify, formulate, and solve complex engineering problems.	Solves textbook equations and controlled laboratory setups.	Formulates engineering problems based on real-world stakeholder requirements and unscripted operational constraints.
Outcome 2: Apply engineering design to produce solutions that meet specific needs.	Designs components to meet instructor-provided specs.	Iteratively designs MVPs that balance public health, safety, and welfare alongside global, cultural, social, environmental, and economic factors.
Outcome 5: Function effectively on a team that provides leadership and creates a collaborative environment.	Completes assigned group lab reports.	Manages cross-functional sprint goals, assigns specialized roles (technical vs. market validation), and executes agile project workflows.

3.3. Tier 3: Commercialization Strategy (Advanced)

Pedagogical Focus and Objectives

This Tier focuses on the evaluation of potential market opportunities based on technology, development of a sustainable business model, analysis of relevant regulations, and delivery of a proposal to invest, transfer, or purchase technology. This Tier is appropriate for upper-level undergraduate students, graduate students (including Master's and Ph.D.), and postdoctoral students.

This Tier focuses on integrating a range of competencies, including the understanding of different types of intellectual property and patent protection, com-

mercialization finance and regulation, entrepreneurship, and the procedures and policies of the university for technology commercialization.

This Tier is typically integrated within the senior capstone projects, and may include Master's students and/or Ph.D. students as commercialization fellows.

- Weeks 1 - 3 (IP & FTO)
- Weeks 4 - 7 (Regulatory & QMS)
- Weeks 8 - 10 (Financial Analysis)
- Weeks 11 - 12 (Tech Transfer & Pitching)

3 **weeks**: Intellectual Property, Patent Searching and Freedom to Operate (FTO)

Locating and understanding patents, prior art and patentability, claim interpretation, patent examples and cases, the University tech transfer process, and IP policies.

4 **weeks**: Regulatory Pathways and Quality Management

Locating and understanding the regulatory agencies (FDA, EPA, FCC, etc.), ISO standards, and Quality Management.

3 **weeks**: Financial and Economic Analysis

Determining and assessing the economic impact and returns from an investment.

3 **weeks**: Technology Transfer, Licensing and Venture Capital

Licensing examples and cases, spinoff examples, dilution, non-dilutive grants, and Venture Capital.

3.4. Comprehensive 3-Tier Execution Matrix

Attribute	Tier 1: Ideation	Tier 2: Validation	Tier 3: Commercialization
Academic Level	Years 1 & 2 (Foundational)	Year 3 & Early Year 4 (Applied)	Senior Capstone/Graduate (Advanced)
Primary Methodology	Human-Centered Design	Lean Startup & Rapid Prototyping	Venture Design & Tech Transfer
Key Risk Assessed	**Problem Risk:** Does anyone care?	**Technical Risk:** Can it be built affordably?	**Market Risk:** Can it make money legally?
Primary Deliverable	Validated Need Canvas	Functional Beta MVP	Investment Deck & Business Plan
Tech Transfer Outcome	Problem identification log	Provisional patent application draft	Spinoff creation or licensing deal

4. Institutional Implementation, Organizational Architecture and Case Examples

[Core STEM Departments] ---> [Shared Maker Space Hub] --> [External Startup Ecosystem]

[Business and Law Schools]

4.1. Cross-Disciplinary Integration Models

Cross-Departmental Senior Capstone Model

The goal of a research university is to educate the future innovators across multiple disciplines. Incorporating a Joint STEM and Business Capstone experience would help foster cross-school collaboration. The elements of such a program are:

- Teams comprised of STEM students and a Business student
- STEM students would satisfy their Engineering School requirement, and the Business student would fulfill their School's Elective or Capstone requirement.
- The program would define and establish joint goals for the teams to achieve.

4.2. Evaluating Educational and Commercial Results

Educating students to innovate, create and launch business ideas is important work. It is necessary to recognize that not all ideas and innovations are commercial successes. Some of the best ideas and innovations may not be commercially successful. Programs and schools must establish metrics for evaluating educational results that are separated from the end goal of commercial results.

1) **Iterative Prototyping Skills**: Ability to modify designs based on user feedback. Assessed by applying multiple rounds of user testing.

2) **Commercial and Ecosystem Impact Metrics**

a) Invent disclosures: Amount disclosed to University's Tech Transfer Office.

b) Startup activities: Student/graduate startup launches, and seed financing.

c) Industry engagement: Student project sponsored industry agreements and sponsorships.

4.3. Intellectual Property

There are a number of reasons why Universities should allow students to own the IP generated from their research; however, there are a number of exceptions.

a) Student Coursework Ownership: IP generated from standard course research should be 100% owned by the student.

b) Institutional Resource Thresholds: IP generated from faculty research should be owned by the University.

c) Sponsored Research Rules: IP ownership should be determined by the terms of the contract.

d) Mandatory TTO Pre-Filing Review: TTO should be notified of the student research.

4.4. Safety, Data Privacy, and Ethics Oversight

There are some additional considerations when students are designing and implementing a project that will be conducted in the field or will include interaction with or exposure to humans (i.e. projects that will be of a medical or scientific nature). Some of those considerations will be covered here.

Review of Ethics (IRB) Process

When students conduct customer discovery or field surveys, the process should

be reviewed and approved by an IRB. Generally, universities should have a streamlined process to approve ethics reviews to cover standard course activities.

Informed Consent

If a student conducts a customer discovery interview and wishes to have the interview recorded, the student should obtain the interviewee's signed informed consent. If the interview is recorded, the student should erase the interviewee's name and other personal identifiable information and store the recorded interview in a secure, closed system.

Clinical and Lab Safety

If a student wishes to test a product in the field or in a clinical setting, the student should obtain approval of the EHS officer.

5. Illustrative Project Examples (Note on Scenarios A and B)

The following two examples are illustrative only and do not represent actual cases. Each of the numbers presented is an approximation and represents a target case or market size.

- Scenario A (Medical Technology Prototype—Illustrative): Tracks the student progression from shadowing doctors (Tier 1), to creating medical devices under various simulated regulation conditions (Tiers 2 and 3).
- Scenario B (Agricultural Analytics Prototype—Illustrative): Tracks the progress students make in establishing benchmarks (for instance, a student-set goal of an 88% pest detection rate), in order to learn about design of algorithms and their field tests, as well as pricing structures.

5.1. National Innovation Policy and Competitiveness

Beyond university campuses, a similar rationale for the need to develop STEMpreneurship exists. In order to enhance its national competitiveness, a country must be able to utilize science and technology to innovate in the fields of critical commercial areas, such as information and communications technology, microelectronics, and other enabling technologies (like quantum computing) and renewable energy. Among other things, the U.S. National Science Foundation's Innovation Corps (NSF I-Corps) demonstrate the potential for academic entrepreneurs to drive innovation and commercialize science.

5.2. Implementation Limitations and Risk Mitigation

Challenge

Risk

How will the risk be mitigated?

Curriculum Overcrowding

Adding new courses to integrate entrepreneurship may result in violations of the accreditation requirements of the Accreditation Board for Engineering and Technology (ABET).

Embed entrepreneurship modules of 4 to 6 weeks in engineering design and lab

courses.

Resource Disparities

Not all universities have maker spaces. Some universities may not have seed funds.

Rely on large research universities to form a consortium and use their maker spaces and digital fabrication facilities. Use NSF's I-Corps to gain industry knowledge and sponsorship.

Equity and Intellectual Property Disputes

In the absence of clear Intellectual Property Policies, disputes may occur.

Universities should adopt Policies that give students ownership of Intellectual Property generated in class.

Author Contributions

RND and LA designed the conceptual framework, authored the theoretical literature review, designed the modular curricula, and wrote the paper. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare they have no competing interests.

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