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Title: Enhancing STEM Graduate Education: The Design, Development, & Piloting of a Course to Promote Research Innovation, Mentoring, and Career Readiness

Topic Area of the Submission: STEM Education

Presentation Format: Roundtable

Description of Presentation:

Join us for a discussion on the ideal components of STEM graduate education. We will present information on the design, development, and piloting of a new graduate course to promote research innovation, mentoring, and career readiness. We will share our experiences working with graduate students in electrical engineering and highlight specific course content and assignments that respond to recommendations from the National Academies of Sciences, Engineering, and Medicine.

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Enhancing STEM Graduate Education: The Design, Development, & Piloting of a Course to Promote Research Innovation, Mentoring, and Career Readiness

Abstract

<u>Project Background and Relevant Literature</u>

Need for a Skilled STEM Workforce: Developing a STEM workforce is critical to our nation's ability to compete globally. In 2015 there were 8.6M STEM jobs (6.2% of U.S. employment). These numbers continue to rise, with an above-average growth rate of 10.5% from 2009-2015 and a projected growth rate of 6.5% in the next 10 years. The national average wage for STEM occupations ($87,570) is almost double that for non-STEM ($45,700). The National Academies of Sciences, Engineering, and Medicine (NASEM) asserts that those with STEM graduate degrees have a deep knowledge base, the ability to think independently, and advanced critical thinking skills that have produced basic and applied research and innovations that have given the U.S. a competitive advantage in the global marketplace.

State of Graduate Education in STEM*:* The U.S. has seen a steady increase in the number of students enrolled and graduating with graduate STEM degrees. STEM programs accounted for 24.7% of all master's degrees and 64.4% of all Ph.D. degrees awarded in 2015. While STEM graduate programs are generally successful graduating students, they may not be meeting the needs of the current workforce. Changes in the nature of work (e.g., multi- and transdisciplinary approaches, collaborative, international), shifts in demographics, rising competition requiring unremitting and striking innovations in technologies and research methods, and a broader understanding of societal and global contexts. Although employers value the analytical, research, and critical thinking skills developed in STEM graduate programs, they find that graduates are missing a variety of other important skills including communication, team work, multicultural competence, mentoring, networking, and leadership. STEM graduate students desire opportunities for career exploration – exploration that would help them understand multiple career paths and make more informed career decisions. This type of exploration makes sense given the increasing numbers of STEM graduates who will have multiple jobs over the course of their career in a range of sectors such as policy, law, media, communications, nonprofits, and government.

Components of Ideal STEM Graduate Education: The NASEM *Committee on Revitalizing Graduate STEM Education for the 21st Century* examined the needs of diverse graduate education stakeholders (faculty, administrators, industry, policy makers, students). They suggested that ideal graduate STEM education will require a systems approach that is student centered, focused on the diverse needs and challenges of graduate students: (1) STEM graduate education should respond to the need for "T-shaped workers" who have broad technical literacy along with deep specialization; (2) students should acquire a knowledge base centered around core competences in addition to having opportunities to understand and consider ethical and cultural issues and the broader impact of their work; (3) STEM graduate education should provide multiple viewpoints of the scientific enterprise, establish a connection between science, engineering, and society, and allow students to grapple with differences of opinion, ideas, and experiences; (4) Project-based learning is encouraged, in which students have the opportunity to learn by doing, work as a team, and present their work to audiences within and outside of their department; (5) Students should be given time, resources, space, and guidance to explore diverse career paths through courses, seminars, internships, mentorship, advising, career counseling, and real-life experiences. The NASEM recommendations serve as a blueprint to develop transferable professional skills -- communication, collaboration, leadership, and entrepreneurship and allow students to fully participate in their education and achieve their fullest potential.

<u>Project Overview</u>

The Pilot: The *Lean Canvas for Invention (LCI)* is a bold, new, and trasformative approach to STEM graduate education and training. In this NSF-funded project, we are piloting, testing, and validating the effectiveness and feasibility of the *Lean Canvas for Invention* program[i], hosted within a course for individual students or research teams (faculty and their students) within the College of Engineering at the University of Utah (UofU).

The Innovation: For this project, we have developed the ***Lean Canvas for Invention (LCI)***, an innovative program to help individual students or research teams think through a problem and identify its *most valuable research questions*, and create both team and individual research and career trajectories. The *LCI* formally guides and mentors both individuals and the team to explore beyond the traditional scientific literature to include innovation triggers (patent literature, business reviews, and personal interactions with stakeholders). Whether or not the research may be commercializable now or in the future, understanding the rich state-of-the-art and culture of the problem space in both academics and industry can expand the knowledge and creativity in the research development process. This approach is used today in startup businesses, but bringing it to an earlier level of the research development process is novel and impactful. To this innovative approach, we will add matrix mentoring[ii],[iii] (a combination of faculty and peer mentors, and industrial liaisons) and formalized career development to better prepare the engaged thought leaders of the future.

Student Population and Justification for Inclusion: The *LCI* approach is particularly relevant to engineering teams where basic research often leads to inventions and then to innovation and commercialization. We are currently applying the *LCI* approach for students and research teams in engineering (Electrical and Computer, Mechanical, Chemical, Civil and Environmental, Nuclear, Bioengineering, Materials Science, and Computer Science). However, we think this course has broader application to STEM graduate education and in the Spring 2024, we are opening this course to graduate students in any STEM major.

Project Goals and Objectives

We have expanded the basic *LCI* to include formalized mentoring and career development. We hypothesize that this novel program will improve graduate education by: (a) helping students develop research objectives and critical thinking and the skills and knowledge to be successful in their discipline, (b) enhance the quality and effectiveness of peer and faculty mentoring to create a more inclusive and supportive research environment, and (c) facilitate professional competencies, vocational literacy, career identity, workforce readiness, and lifelong career management for a broad range of careers.

Objective 1: Apply an innovative tool, the ***Lean Canvas for Invention,*** to graduate research development in engineering. We have recently piloted the research development portion of the *LCI* with good success, which we will build upon in this project. *Specific Goals:*

- Implement a **formal approach** to problem exploration, creative ideation, and research development that guides and challenges both experienced (faculty) and novice (students) researchers.
- Utilize a **team-based structure** that provides support for both faculty and students over the dynamic life of a project that spans many years, many students, and many (likely multidisciplinary) collaborators.
- Employ an **easy-to-adopt** approach that is a natural fit to team-based research.
- Expose students and faculty to the **full innovation landscape** of identifying and thinking through a key research problem that leads to **innovation and commercialization potential** of their inventions.

Objective 2: Optimize the **quality and consistency of mentoring** and relationships within the research team. In this project, we will be adding formal mentoring components to the *LCI*. Specific *Goals:*

- Integrate a **matrix mentoring model** that supports the individual career trajectories of all team members by establishing ongoing interactions among peer, faculty, and relevant external stakeholders
- Provide **training, resources, and a platform** through which mentoring can occur on a regular and structured basis, providing cultural competence for the team members.
- Enhance student and faculty **sense of belonging** to the research team, academic department, and field of engineering by valuing individuals' professional and cultural backgrounds
- Increase students' **research and innovation self-efficacy** and enhance career development, persistence intentions, academic success, and the efficacy of mentoring.

Objective 3: Foster graduate students' professional competencies, career literacy, career identity, workforce readiness, and the ability to make informed decisions regarding their career paths. In this project, we will formalize, expand and enhance these aspects of the *LCI*. *Specific Goals:*

- Develop the **skills, knowledge, and competencies** necessary for the range of engineering careers.
- Identify career aspirations and action steps to create a **dynamic individualized career development plan**, which will be reviewed at specific time points and at an ongoing basis.
- Provide students and faculty with **resources** on preparation for diverse non-academic career paths.
- Facilitate **structured networking and career exploration** through quality formal interactions with professionals in engineering-related industry.

<u>Course Curriculum</u>

Curriculum Component 1 -- The Lean Canvas for Invention (LCI):

The *Lean Canvas for Invention* (*LCI*) (Fig. 4) is a new approach that we developed based on the *Lean Canvas for Business* (*LCB*)[iv] (Fig. 3) that has been taught at Stanford, Berkeley, Columbia, and Caltech and has been adopted by NSF[v] and NIH[vi] i-Corps. This program ("canvas") shortens ("leans") product development cycles by adopting business-hypothesis-driven experimentation, iterative product releases, and validated learning[vii,viii]. Entrepreneurs talk to stakeholders (customers, partners, competitors, etc.) and encounter the chaos and uncertainty of commercializing innovations. The *LCB* has been adapted and leveraged extensively at the UofU, and is one of the keys our innovation ecosystem success. Applying this model after recently submitting invention disclosures, many researchers have said they wished they had gone through the stakeholder reviews at the beginning of their research process, and that it could have made their thinking even more innovative and more likely to be applicable in the real world.

The Lean Canvas for Business identifies the Minimum Viable Product for a startup business. The Lean Canvas for Invention helps researchers at an early stage in the invention-innovation cycle identify their Most Valuable Research Questions.

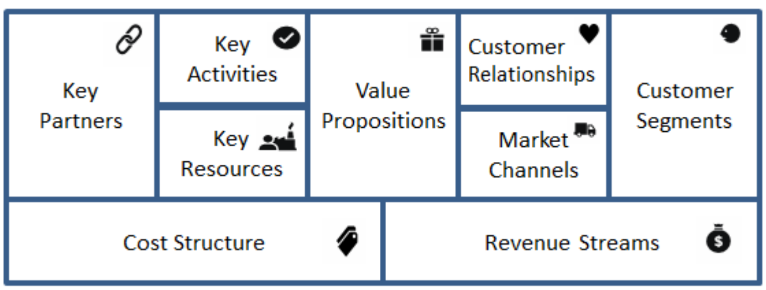

*Figure 3: **The Lean Canvas for Business (LCB)** is used for NSF and NIH I-Corps training. Participants fill in the canvas information via in-person stakeholder interviews, pivot their business theories based on these interviews, and identify a minimum viable product (MVP) in a realistic market. The Canvas is stored, accessed, and assessed via a mature set of online tools.*

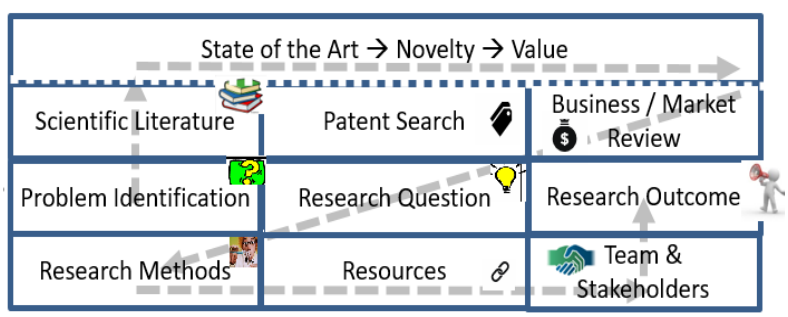

*Figure 4: **The Lean Canvas for Invention (LCI)** follows (see the Z-shape) the full dynamic life of the research process from the earliest problem identification, through an evaluation of novelty and value to identify the most valuable research question, then through the research methods and resources (including the team and stakeholders) to a valuable research outcome, which would then lead into the LCB (Figure 3).*

In addition, through the Lean Canvas experience, a social network is formed that benefits the research, mentoring, and career development of the individuals and the team. This program formalizes the team-based research development process that is common in engineering and adds three significant components that are typically ad hoc or missing entirely (1) Exploration of the full state of the art, including patent literature and business / market reviews (e.g. is this area growing, in what ways, what are the major barriers to growth, what regulations apply, what policies are in play?), (2) Two-way interaction with a wide variety of stakeholders (e.g. rather than a traditional model of teaching students to speak to diverse audiences, this program engages students in asking and listening to the perspectives of diverse audiences that interact with their field, also providing early opportunities for interaction and networking within their professional community), (3) A natural, **team-based** approach that is based on the work a research team is normally engaged in, yet simultaneously provides a program that provides best-practices in mentoring for all team members (students and faculty) through a matrix mentoring model. (What do we mean by "natural"? – a method that follows the typical research process, providing just-in-time support in ways that fit easily with both students and faculty, a method that is easy to adopt, because it makes existing work easier.)

Curriculum Component 2 -- Mentoring and Graduate Student Socialization

The *LCI* provides a scaffolded learning environment for engineering graduate students and research teams. In addition to development of domain-specific skills (e.g., identifying research questions; translating research into innovation), we propose mentorship for student socialization and preparation infused into each *LCI* process. Our *LCI* model optimizes a team-based structure, in which faculty and students complete the research development process together, supported by a matrix mentoring approach.

Improving Mentorship in Engineering Graduate Education*:* At many critical points throughout the STEM pipeline, including high school, college, and graduate education, mentoring emerges as a significant predictor for scholarly productivity[ix], persistence attitudes within STEM-related fields[x], and career outcomes or intentions[xi]. According to NASEM[Error! Bookmark not defined.], institutions are highly encouraged to leverage their resources to provide faculty with training to enhance their mentoring skills, including time to develop their abilities to advise and supervise their graduate students. In contrast to the traditional faculty-protégé approaches to mentorship (e.g., bestowing of field-specific knowledge from expert to novice), the NASEM report illuminates the importance of cultivating lateral mentor-mentee relations. Optimal mentorship in STEM graduate education involves the careful consideration of both mentor and mentee' cultural backgrounds and salient social demographics. For example, studies indicate STEM racial-ethnic minority students experience a lack of belongingness within their programs, encountering implicit bias (e.g., racial microaggressions) as well as explicit racial discrimination during their training [xii,xiii]. Culturally responsive mentoring (e.g., mentors explicit acknowledgement of mentee's cultural identities) of underrepresented STEM students is associated with students' positive academic and career self-efficacy[xiv]. Further, a study on the preparation of the new generation of STEM faculty[xv] revealed graduate students' professional development is influenced by several non-cognitive factors, including age, education, and employment.

Graduate Student Socialization through Mentorship: The concept of socialization has been central to research on the graduate education process[xvi]. Graduate student socialization is commonly defined as a process of developing the skills and knowledge and gaining an understanding of the norms and values of the student's specific field[xvii]. Socialization processes are bidirectional in that students are influenced by and also influence the culture and values of their department are equally accountable for considering how their practices, including mentoring, are implemented.

Graduate student socialization has been further described as a process involving three components, including (a) interaction and engagement with faculty and peers, (b) integration and sense of belonging with peers, and (c) the development of the knowledge and skills necessary for professional practice[xix]. *Access to knowledge and resources has been upheld as an extremely critical aspect of graduate education and predictive of whether graduate students are well-prepared for careers and their overall persistence[xx]. A staged model explicates how students receive the necessary information to succeed and to develop key factors involved in building cognitive maps, enabling students to navigate the graduate school terrain. For example, early stages of graduate student development involve learning about their department, becoming exposed to the research being conducted by faculty members, and early interactions with faculty and peers in the department. In later stages, students become oriented and undergo a period of role induction in which mentoring is a key component. During this period, students' main tasks are to develop field-specific competencies through formal coursework, collaborate with faculty on research, receiving consistent and quality mentorship on project planning. This staged model explicates the importance of providing structures for informational access, efficient completion of degree requirements, and consistent and useful connection with faculty and peers. Moreover, it highlights the role of the academic department, as the primary* *mechanism through which students develop their identities as respected and invited members of a scholarly community. The LCI program nicely aligns with these developmental stages by addressing the specific needs of students based on their year of study or earlier professional experiences.*

Matrix Mentoring: A Sustainable Approach: Matrix mentoring, broadly involving faculty and peers, plus self-reflection, has been shown to be more effective than single-factor mentoring alone.[xxi,xxii] One of the objectives of the *LCI* is to integrate best practices in mentoring graduate STEM students into a readily-adopted program that guides both faculty and students in a strong matrix mentoring model.

Our *LCI* curriculum, described in Table 3, naturally integrates just-in-time mentorship training with (a) assignments pairing senior with junior graduate students, (b) consistent discussion and check-ins with faculty and among members of the broader *LCI* group, (c) progressive mentoring activities[xxiii] that scaffold learning expectations and responsibilities of each *LCI* group member based on their experience and position (e.g., 1^{st} vs. 4^{th} year students), and (d) a 360° approach engaging all members in giving and receiving feedback. Matrix mentoring leverages a team-based strategy where students learn and practice mentorship and actively mentor junior students, faculty enhance their mentorship skills by learning from the students, and everyone develops professional and interpersonal skills to navigate multiple work contexts.

The LCI program used in this project responds to the NASEM[Error! Bookmark not defined.] *findings by providing structured and ongoing opportunities to develop mentoring competencies and enhance engineering graduate student socialization experiences. Throughout the program, students and faculty develop a mentoring plan, including a contract outlining their expectations and objectives for mentoring relationships. Mentors will include faculty and senior and peer students (e.g.,* 2^{nd} *year students will mentor* 1^{st} *year students). The mentors with whom students and faculty will interact will also grow as they being to meet external and industry-based mentors.*

Curriculum Component 3 -- Professional and Career Development

Core Competencies for Graduate STEM Education: Core educational elements e.g. coursework, research, internships, professional development (see Table 1), make up a STEM graduate program. Graduate education should "…stimulate curiosity; develop the intellectual capacity to recognize, formulate, and communicate complex problems; create an iterative approach toward solutions, drawing from discipline-appropriate quantitative, theoretical, or mixed-methods tools; make original discoveries that advance understanding; and communicate the impact of the research beyond their discipline"[Error! Bookmark not defined.].

The LCI program used in this project responds to the NASEM[Error! Bookmark not defined.] *recommendations by incorporating each of the identified core elements into the LCI course. Further, the skills, knowledge, and competencies associated with these core elements are made explicit, documented, and evaluated.*

Table 1: The NASEM[Error! Bookmark not defined.] **(2018) suggested that students in STEM graduate training programs should acquire skills, knowledge, and competencies within these core elements:**

Core Element	Skills, Knowledge, & Competencies
Scientific & Technological Literacy	Develop deep specialized expertise in at least one STEM discipline
	Acquire sufficient transdisciplinary literacy to solve complex problems
Original Research	Identify an important problem and articulate an original research question
	Design a research study to address the research question
	Evaluate the outcomes of each experiment or study component and select which outcomes to pursue and how to do so through an iterative process
	Adopt rigorous standards of investigation
	Acquire mastery of quantitative, analytical, technical, and technological skills
	Understand and apply professional norms and practices of the scientific or engineering enterprise
	Learn ethical responsibilities and apply ethical principles and standards

Leadership	Learn how to effectively lead teams and manage others
Collaboration & Work in Teams	Develop the ability to work in collaborative and team settings
Communication Skills	Acquire the capacity to communicate orally and in written form to STEM professionals and the public at large
Professional Competencies	Interpersonal communication, Multicultural competence
	Project management, Budgeting

Need for Career Information, Exploration, and Development in Graduate Training Programs: Graduate training programs in STEM may not be meeting the career development needs of their students. Graduate students in STEM consistently describe the desire to be provided with opportunities for career exploration – exploration that would help them understand multiple career paths and make more informed career decisions[Error! Bookmark not defined.,xxiv,Error! Bookmark not defined.]. This type of exploration makes sense given the increasing numbers of STEM graduates who will have multiple jobs over the course of their career in a range of sectors such as policy, law, media, communications, nonprofits, private enterprise, and government[xxv]. Moreover, the path from graduate student to world-of-work is not always linear. Students may have entered graduate school thinking they will pursue one specific career pathway, but may change their mind as they obtain knowledge and experience in the field and receive career information from faculty, peers, or alumni, and are exposed to a range of interesting and exciting alternative career paths. A national survey found that 33% of students in doctoral programs became less interested in faculty positions while 20% became more interested[xxvi]. Students felt that encouragement to consider nonacademic careers was limited. Another survey reported that 39% of graduate students changed their career goals during their program. Thus, graduate school may refine and re-define career aspirations and expectations. The Council of Graduate Schools and Educational Testing Service suggests that academic programs provide appropriate training, mentoring, and career exploration opportunities to help graduate students understand the career options available to them.

The LCI program provides students with career information, exploration, and development. As described below, students will create a dynamic individualized career development plan, reviewed regularly.

Barriers to the Development of Core Competencies: A number of barriers have been identified by NASEM[Error! Bookmark not defined.]. First, even when universities provide opportunities for the professional development, these offerings may not be well publicized or may vary in degree of effectiveness. Professional development opportunities may also be underutilized when graduate students do not know how to take personal responsibility for competencies outside of their research field (e.g., leadership, collaboration, project management). For a number of reasons, professional development opportunities may not be encouraged by the primary research advisor or academic STEM department. Given the stigma associated with nonacademic careers (in some fields of study), students may shy away from opportunities to explore nontraditional careers. Moreover, faculty may not have the expertise or first-hand experience to provide guidance in exploring nonacademic careers. From a programmatic perspective, there is the issue of time and money. Academic departments may fear focusing on these competencies will dilute discipline specific coursework, increase time to degree, and stress students, faculty, and budgets. The NASEM[Error! Bookmark not defined.] calls for more research to determine how professional development activities can be incorporated into existing curricular structures and how they would impact STEM graduate education.

The LCI program responds to these identified barriers. Professional development opportunities and career exploration will be incorporated into the LCI, faculty and students will be trained in providing quality mentoring, and outcomes will be measured, written up, and disseminated widely.

<u>Novelty and Intellectual Merit</u>

This project examines the impact of the *LCI* program. We hypothesize that this novel program will improve graduate education by: (a) Helping students develop their research objectives and critical thinking and develop the skills and knowledge, (b) enhance the quality of peer and faculty mentoring to create a more inclusive and supportive research environment, (c) facilitate students' professional competencies, vocational literacy, career identity, workforce readiness, and lifelong career management for a broad range of STEM careers. To evaluate the effectiveness of the LCI program, we will include a control group of students and faculty who do not participate in the team-based intervention. In addition, an overarching ethnographic research approach will be used to monitor the *LCI* processes across the grant and integrate the assessment and evaluation activities for all three curriculum components[xxviii,xxix]. Observations (fieldnotes), artifact analysis, reflections, and debriefs, will help to visualize the *LCI* pilot grant activities, interactions, and work culture. Ethnographic data will be used to identify future *LCI* curriculum improvements.

Accomplishments to Date

Assignments and course content were designed and developed around the three topics of: engineering research using a Lean Canvas framework, mentoring development, and career development. This course (ECE 6960) was designed and developed in the learning management tool Canvas.

This course has been offered twice – in the Spring 2022 semester and the Fall 2022 semester. In both instances, students attended class for an hour each week via zoom and then completed readings and assignments outside of class within the Canvas course room.

We tried offering this course in-person in the Fall 2023 semester, but the course enrollment was so small we had to cancel the course.

We plan to offer the course in Spring 2024 as an asynchronous course in the Canvas platform. We are currently revising the curriculum to ensure it is generalizable to students in other STEM domains.

Preliminary Research Results

Although students reported benefiting from all three of the course topics, the highest scores when ranking the assignments were in the Learn Canvas research assignments. The assignments with the highest scores in the Lean Canvas assignments were related to identifying their research problem, citation formatting, and conducting stakeholder interviews.

Under the topic of career development that most valued assignments were related to completing and reflecting on the my IDP (individual development plan), doing an elevator pitch, and learning about interviewing.

In the mentoring development section, the highest scoring assignments were those that focused on setting mentoring SMART goals, establishing mentoring expectations and boundaries and learning about culturally responsive mentoring.

One student commented, "We talked about the soft skills you need as an engineer, but aren't talked about in other classes." This topic of valued-added course topics kept recurring over and over. Although students felt overwhelmed with the number of assignments (which we will work on improving in the next course), they felt all three topic areas (research, career development, and mentoring skills) were all important. One student reported that they were sharing what they learned with their peers and research team members.

Students completed pre-class and post-class survey instruments. Our findings show increases in the mean scores on measures of engineering interest, engineering self-efficacy, engineering persistence intentions, and STEM self-efficacy beliefs. Our findings also show decreases in the mean scores on a measure of barriers. Specific barriers that decreased include: lacking confidence in my academic skills, experiencing discrimination, uncertain of my career goals, lacking support from my instructors, lacking support from my family or friends, not having a role model or mentor, feeling anxious or overwhelmed, and feeling bored. Unfortunately, post-class survey results indicate that some barriers increased over time: financial strain, test anxiety, work-life balance, and depression. At the same time, these barriers may be more indicative of finals week than a result of the class.

Acknowledgement:

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