Pathways to Entrepreneurship (PAtENT) Program: Reimagining STEM Doctoral Programs

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Abstract

This Work in Progress paper describes the development and implementation of a new pathway for doctoral candidates in STEM programs to satisfy their capstone degree requirements that has the potential to modernize the STEM Ph.D. The model, Pathways to Entrepreneurship, aims to bring greater alignment between doctoral degrees and the rapidly changing employment landscape. Programmatic and curricular innovations to the current Ph.D. model are described along with the rationale. Project goals are to develop an alternative roadmap for STEM doctoral students, that is scalable, and to investigate pedagogical implications of these innovations, for doctoral education and for broadening participation of women, veteran students, and those traditionally underrepresented in STEM. We present the assessment approach to evaluate program efficacy, and share baseline information regarding student self-efficacy toward entrepreneurship. The aim of this project is to increase entrepreneurship rates among graduates, and to propagate evidence-based practices to STEM graduate programs. Should our innovations be adopted by other programs based on our anticipated findings, a separate *Doctor of Innovation* track might emerge as a viable alternative to the current *Doctor of Philosophy* track.

Introduction

The current operational paradigms in graduate STEM education, and doctoral programs in particular, took shape in the years following the Second World War, and have seen little structural or philosophical changes in the period since. In recent decades, workforce needs and the employment landscape for STEM graduates has experienced fundamental changes in scale and scope. While the number of STEM-related jobs has risen significantly [1], [2] the range of STEM careers has also expanded sharply [1], [2] . In the recent National Academies of Sciences, Engineering, and Medicine study report focused on Graduate STEM education for the 21st century [3], the authors observe that "Indeed, recent surveys of employers and graduates and studies of graduate education suggest that many graduate programs do not adequately prepare students to translate their knowledge into impact in multiple careers." In spite of the accelerating pace of these changes and varying demands on graduates entering the contemporary workforce, the fundamental structure of the STEM doctoral program has remained unchanged.

The current paradigms in doctoral programs are such that the incentives for both faculty and student performance are aligned towards growing the research enterprise at the faculty, institution, and research community levels, and not always focused on preparing students for the dynamic requirements of the modern workforce. In this current model, the key milestones [3], [4] are (i) discipline-specific coursework, (ii) identification of a dissertation advisor and appointment of a dissertation committee, (iii) comprehensive subject matter exams, (iv) supervised research culminating in the publication of peer reviewed journal papers and a dissertation, and (v) defense of the dissertation. This structure ensures students graduating with a STEM doctoral degree acquire a deep and rigorous grounding in their areas of specialization, while making original contributions often published in the open scientific literature. However, several drawbacks of this structure have been identified due to recent developments in the knowledge economy and the STEM workforce. First, the current model represents a lack of flexibility in the pathway to a Ph.D. and does not sufficiently cater to the increasingly varying needs of both employers and graduates. As the graduate student body grows more diverse, especially in regard to the diversity of backgrounds and of expectations, doctoral programs must adapt to provide multiple pathways to satisfy the degree requirements. Second, while doctoral programs impart technical skills and expertise through rigorous training, transferable professional skills, such as entrepreneurship and management, are not sufficiently addressed. Finally, the current approach is not student-centered, since the emphasis lies in advancing the research enterprise, rather than on student career interests and professional skill development.

Given that 74% of Engineering Ph.Ds. are employed in industry, and only 12% in academia [5], preparation for entrepreneurial careers is needed. The economic impact of research and development is substantial, with a greater return on investment to the US economy than that of stocks [6]. However, just 4% of US patents are awarded to the academic sector [7]. The need to prepare doctoral candidates for research and development careers is essential if we are to modernize academic programs to align with workforce demands.

A student-centric approach changes the educational emphasis toward the development of a range of skills required to compete in the modern and rapidly changing knowledge economy, and provides a flexible pathway without compromising the technical rigor or the original intent of the program. Alternative pathways to the current Ph.D. must ensure that the core elements identified as essential to all Ph.D. education programs in the NAS report from its Call for Community Input [3] must be delivered. These core elements are (i) the development of scientific and technological literacy, and conducting original research; (ii) developing leadership, communication, and professional competencies [3]. Such changes to the doctoral curriculum must not increase the student's overall academic load or adversely affect the time-to-degree [3]. The Pathways to Entrepreneurship, or PAtENT program, is an innovative alternative to the current doctoral roadmap. It is a novel pilot study that ensures the core elements of STEM doctoral education are delivered, while satisfying the multiple requirements and needs to address the evolving workforce and to become student-centered.

The goals guiding the PAtENT study are as follows. We aim to develop an alternate pathway, i.e. roadmap, for STEM Ph.D. students that is scalable and reflective of the evolving employment landscape and workforce needs. The pedagogical implications of these innovations will be investigated via original pedagogical research hypotheses and application of a detailed evaluation and assessment component. Expected outcomes include the development of strategies to broaden participation of female and veteran students in doctoral programs at our university, and the propagation of successful strategies to other universities.

The PAtENT Program's Innovative Roadmap

The PAtENT program will ensure students do not enroll in additional coursework, but instead offer an alternative pathway toward the doctoral degree. The PAtENT program thus represents a philosophical paradigm shift in the STEM Ph.D model, where we acknowledge rigorous scientific research can, and is often necessary to, pave the way for commercialization of technology. This need necessitates a new way of thinking about what the STEM doctorate should represent in the context of catalyzing the formation of technology startups.

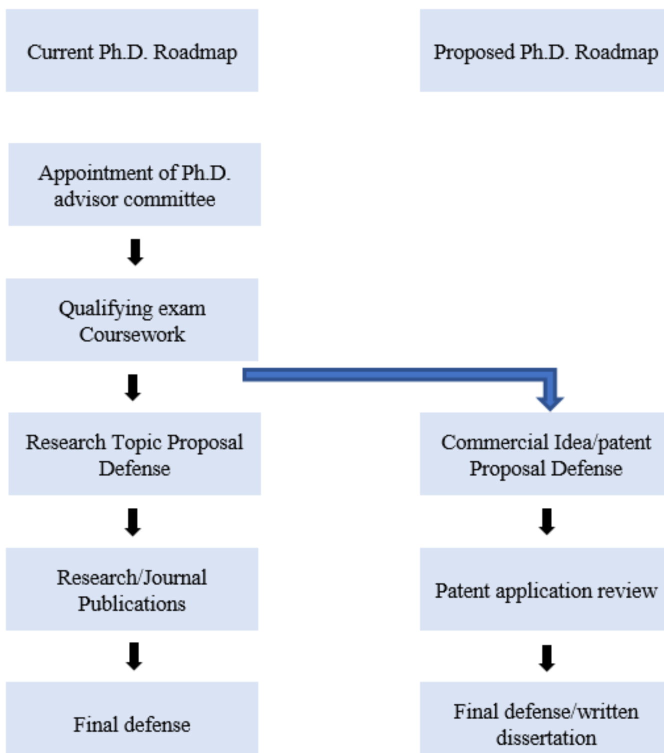

Figure 1. Current and New Ph.D. Roadmaps

The PAtENT alternative pathway to Ph.D. allows students to satisfy their degree capstone requirements through the development of patentable technology and the submission of a peer-reviewed patent application. The proposed roadmap is contrasted with the existing paradigm (Fig. 1). Following the appointment of the student's Ph.D. committee and the subject matter comprehensive exam (steps that will be common to both approaches), students are given the option of pursuing the alternative path in Figure 1 based upon the direction of their research and its potential for development of patentable technology. The research topic proposal is replaced with a defense of the patent proposal for the alternative pathway. Satisfaction of this requirement will be based on input from the dissertation committees and the university patent review committee. Students will be allowed to submit patent applications following feedback from the external review committee, which forms the basis for the written dissertation and final defense. When applicable, dissertation publication of individual chapters may be embargoed until the outcome of patent applications are determined. In cases of negative feedback from the external review committee, students consult with their dissertation committee on an appropriate path forward including reverting back to the original track.

The central innovation of this new doctoral roadmap is that it allows multiple pathways from which the students may choose, dependent upon the direction of their research and developing interests. Students whose preliminary research reveals the potential for technology applications can choose the PAtENT pathway in consultation with their dissertation committee, and enroll in doctoral level management courses. The programmatic innovations are coupled with complementary curricular changes which include coursework and training boot camps to prepare students to pursue the entrepreneurial career track. The PAtENT pathway does not add to the total academic load or the time-to-degree of Ph.D. candidates.

Context

UNC Charlotte is an urban research university with over 30,000 students enrolled. There are seven colleges, which offer 19 undergraduate degree programs, and 25 graduate degree programs. The student body is diverse, representing the urban context, with 16% African American, 11% Hispanic/Latinx, and the majority being first generation college students. The College of Engineering has 6 departments: Civil and Environmental Engineering, Computer Science, Electrical and Computer Engineering, Engineering Technology and Construction Management, Mechanical Engineering and Engineering Science, Systems Engineering and Engineering Management. There are 3660 students enrolled, 488 of whom are graduate students, 235 are doctoral students. The College has offered doctoral degrees since 2014. A total of 235 doctoral degrees were awarded in Fall 2020 in Engineering, with 23% of those graduates women, and 4% to African American or Hispanic/Latinx students.

The College of Business offers 8 degree programs with 4703 total enrollment. In 2020, there were 488 graduates from the College of Engineering, and 829 from the College of Business. The PAtENT pathway is enrolling the initial cohort currently, and launching the activities, research and evaluation activities described next.

Program Activities

The PAtENT study is housed in the Mechanical Engineering and Engineering Science (MEES) Department, and involves participating students and their faculty advisors from MEES, Civil Engineering, Physics and Optical Sciences, and Chemistry. Research projects with faculty participants that are on the patent-track have been defined from showing early potential to be patentable, and represent a range of maturity of the commercialization potential for patent readiness. Based on the maturity of the research and technology development, the projects are organized into two cohorts whose entry into the PAtENT pathway will be staggered across years 1 and 2. Group 1 represents more mature projects and enters the program in year 1, while Group 2 is onboarded in the second year of our study. The staggered entry process allows the PAtENT faculty to implement a process of continuous improvement and iterative design where lessons learned from Group 1 can be applied in fine tuning the pathway model for Group 2. Figure 2 provides an for an overview of how students progress through the patent roadmap.

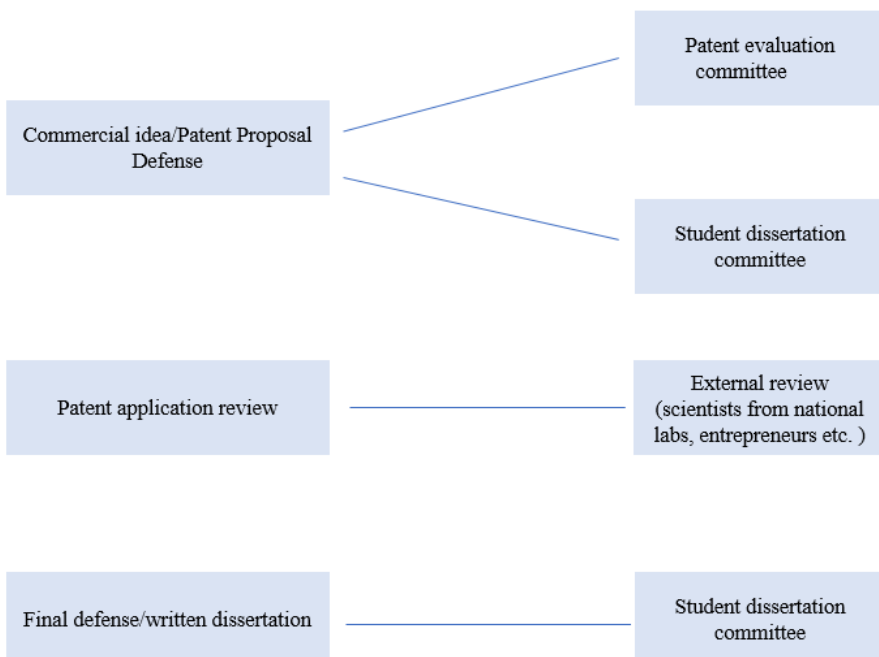

Figure 2. PAtENT Program Student Progression

There are several key components of the PAtENT program. Technical rigor is maintained in the PAtENT program through the appointment of an external review committee (for each project) that performs a single-blind review of the technical merits and commercialization viability of the patent application prepared by the student participants. We leverage the resources and expertise available at Ventureprise, the university's innovation and entrepreneurship center, which provides resources and expertise for university-based startups as they commercialize innovations and scale commercial enterprise. The PAtENT pathway includes two six-week training modules delivered by the Center with the module topics depicted in Figure 3. Additionally, the Business School provides courses to students participating in the PAtENT pathway to compliment the entrepreneurship and innovation focus.

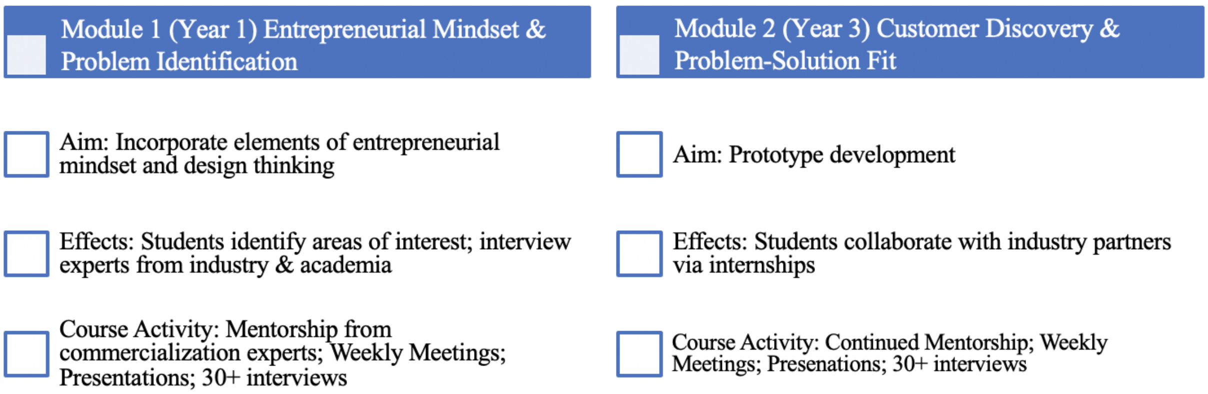

Figure 3. Modules for PAtENT Program

Research Approach

Experiential education has a long history in undergraduate STEM education though the research base about the value of such experiences is sparse [5], [6]. This research points out the benefits of such experiences to cognitive development, improvement in communication and interpersonal skills, and promoting the establishment of career goals. Despite the assumed positive outcomes, STEM doctoral programs have been slow to respond to the changing graduate ecosystem [3]. The PAtENT project responds to these challenges with these key hypotheses guiding the research about the new doctoral pathway's impacts on students and potential for propagation at other institutions.

Research Questions	Data Evidence
R1: Does the patent-focused doctorate contribute to positive development of candidates' STEM and entrepreneurial self-efficacy? If so, how, and if not, why not?	· Repeated measures student survey in computing, business and engineering doctoral programs; Comparison of PAtENT track to traditional track · Redacted Center Name Modules outcomes
R2: Does the patent-focused doctorate align to core scientific and professional elements that have been identified as characterizing doctoral education, and thus provide a model that can be successfully adapted for other graduate programs and institutions?	· Curriculum Map Analysis · Dimensions of Scale rubrics with faculty input

Figure 4. PAtENT Program Research Questions

Evaluation Approach

While the research focuses on agile understanding of curricular improvements across multiple settings, the overall evaluation will focus on the PAtENT track itself. Developmental evaluation approaches [7] fit well within scientific learning communities, because of their focus on learning and collective intervention design, which considers the respective educational contexts [8]. To integrate a responsive evaluation practice characteristic of organizational learning [9], the evaluation is designed by the project leaders (PI Team, Research & Evaluation Committee) in collaboration with the Advisory Boards (External, Student) as the PAtENT degree program unfolds. The approach embraces principles of continuous improvement, community ownership and knowledge, evidence-based strategy, capacity building, organizational learning, and accountability. Key to these approaches are the immediate and iterative review of information with guided discussions among stakeholders (PIs, Faculty, Advisory Board Members, Students) about the interpretations of findings so that any necessary pivots can be identified early with improvements made rapidly.

The evaluation deploys a mixed-methods design following the five dimensions of scale [10] to assess development and propagation of the pathway model: ***depth, sustainability, spread, shift, evolution***. These dimensions provide a wrapper to frame the study objectives, and while distinct, these dimensions are not mutually exclusive. Figure 5 describes the scale. Direct measures include surveys, polls and interviews developed for current students, faculty, and reflective questions for leadership teams and advisory board members. A survey has been developed to capture student beliefs in their academic and professional abilities, with the following constructs of interest: Self-Efficacy scales developed specifically for engineering [11] and for entrepreneurship [12]; Innovation scales to measure creativity, teamwork, initiative and networking [13]. Additional tracking includes participation in Bootcamps, use of Ventureprise Center Modules, and attainment of Entrepreneurship Certificates, along with learning outcomes measures within each.

Formative evaluation measures such as pulse-check polls, are deployed periodically among stakeholders: faculty advisors rate the approach, students rate their experiences, and project leaders and Advisory Board members provide pulse checks about the process, progress, and insights. Indirect measures include national and regional measures of doctoral program enrollment and completion demographics, patents filed, and start-up business within the region. Quarterly meetings review and discuss accumulated data about the PAtENT program. Summative assessment includes annual reports containing results from the formative inquiry, along with key outcomes as they emerge.

Depth
Measures yield quality of the pathway model , e.g. student enrollment, demographics, and learning outcomes within the doctoral program tracks, and innovations developed.

Sustainability
Measures participation in the PAtENT track, adoptions across additional STEM programs within the pilot institution, and feedback from project leaders.

Spread
Measures the extent to which other institutions express interest in the PAtENT Roadmap model that is developed and their ability to adopt and deploy the new approach for doctoral programs.

Shift
Measures the evolution of the model within the various departments that deploy the model; as a leading indicator, the pilot institution is measured while lagging indicators are planned for later project phases, e.g. feedback from constituents who plan and implement deployment at external institutions.

Evolution
Measures the learning that occurs within the pilot project team, across all stakeholders, which will inform propagation of the model across other contexts.

Figure 5. Five Dimensions of Scale Guiding PAtENT Evaluation

Accountability measures include student demographic data within the following areas: enrollment in program tracks of traditional and PAtENT, time-to-degree, and total academic load of the proposed changes, in relation to the baseline (key metric: diversity composition); student learning outcomes (milestones accomplished such as publications, proposals, defenses); career plans (academic, entrepreneurial); additional educational constructs as determined by the pedagogical expert. Overall program learning is assessed via a rubric developed to assess the 5 Dimensions Scale, Figure 5 [10] from the project leadership team, Scalability Committee, External Advisory Board, and the Student Advisory Board. The evaluation logic model, presented below in Table 1, outlines the project goals, actions, key measures, and leading and lagging outcomes.

While the ultimate goal of the project is to increase the number of innovations and entrepreneurialism of doctoral graduates, along with the proportion of degrees earned from targeted student groups, it is not possible to capture longitudinal impacts in the 3 year study timeline. *Therefore, the evaluation includes leading indicators to measure progress*, primarily: doctoral enrollment, persistence and graduation demographics, student self-report of academic and career plans, and term to term milestones (e.g. subject matter exams, publications, proposals) and persistence in doctoral programs by track. Each of these measures are examined by demographics with a focus of attention on students from diverse racial/ethnic groups, socioeconomic backgrounds, and gender representation.

Table 1. PAtENT Program Evaluation Overview

Goals & Objectives	Key Activities	Sample Data & Measures	Short Term Outcomes	Long Term Impact
Create Doctorateof Innovation roadmap to address changing workforce landscape				
Align roadmap to core scientific & professional elements of doctoral study Develop doctoral education strategies to broaden participation Measure scalability	Pilot PAtENT pathway to PhD Track lessons learned Target recruitment Monitor persistence Compare groups Collaborate with Stakeholders	Student surveys: self-efficacy, entrepreneurial attitudes, career plans Milestone achievements Enrollment, Persistence, Graduation Comparions: areas of study & nat'l benchmark data Dimensions of Scale ratings	Formative Evaluations Student Case Exemplars Dimensions of Scale ratings Summative Evaluation Project Dissemination	**Depth:** Rigorous PhD Pathways **Sustainablity:** Support from STEM Depts. at Pilot University **Spread:** PAtENT Model that can be applied across contexts **Shift:** STEM workforce with increased diversity & innovation **Evolution:** Capacity building for model propagation

Curriculum Analysis

A dimensional core curriculum analysis [14], [15] is underway focusing on the core scientific and professional elements identified by The Committee on Revitalizing Graduate STEM Education for the 21st Century [16]. These core elements include the development of scientific and technological literacy and conduct of original research; and the development of leadership, communication, and professional competencies (pp. 106-107). In our analysis we will continue to review program components including documents, artifacts, and other data related to coursework, original research, student classroom experiences as well as laboratories and fieldwork. Initial findings suggest that programmatic core elements and the knowledge and skills outcomes from the doctoral program align to the core elements identified by the Committee. We have begun our analysis process by focusing on document analysis, questionnaires, and other program records. This work is expanding to include focus group interviews, structured and semi-structured student interviews, performance assessments, observations, tests and other assessments, additional document analysis and questionnaires [17]. These components will include both candidates and faculty in both the proposed and traditional doctoral tracks.

As indicated in Table 2, our initial analysis of some program documents shows alignment to 3 of the 7 elements for component 1 and 1 of the 3 elements for component 2. Future work will extend analysis to identify additional supporting activities for these elements and extend documentation to the other elements. This initial curriculum analysis provides early indicators that support program components addressing scientific and technological literacy, and opportunities for students to develop leadership, communication, and professional competencies. This curriculum analysis will be an ongoing process to identify strengths of the program and as a formative tool for program leadership in program modifications.

Table 2. Program Activities Aligned to Graduate STEM Education in the 21st Century Framework

Component	Element	Aligned Activities
Component 1: Develop Scientific and Technological Literacy and Conduct Original Research	Acquire sufficient transdisciplinary literacy to suggest multiple conceptual and methodological approaches to a complex problem	Required to enroll in two courses offered by College of Business on Entrepreneurship and Innovation
	Design a research strategy, including relevant quantitative, analytical, or theoretical approaches, to explore components of the problem and begin to address the problem	Dissertation committee evaluates the student's progress towards the research goals (as outlined in the proposal defense)
	Adopt rigorous standards of investigation and acquire mastery of the quantitative, analytical, technical, and technological skills required to conduct successful research in the field of study	Consider the viability of the patentable technology (as determined by the patent committee), and the as well as input received from the external peer review of the proposed technology
Component 2: Develop Leadership, Communication, and Professional Competencies	Develop professional competencies, such as interpersonal communication, budgeting, project management, or pedagogical skills that are needed to plan and implement research projects	Entrepreneurship focus courses (Business) focus on product- and technology-specific strategies and case studies for market research, customer discovery, decision making, financing, team management, and product management

Student Baseline Survey

A survey was developed to capture student attitudes about entrepreneurship and innovation skill, and distributed to all currently enrolled doctoral students (n=421) in three umbrella degree programs across the university: Business, Computing, and Engineering programs. The baseline survey launched in Spring 2021, and obtained 32 responses to date. The response rate at this time is low, and no generalizations across the doctoral student population can be made yet. However, the survey will be collected throughout the spring term as a measure of future comparison among doctoral students by programs. Means and standard deviations from the current sample are presented in Table 3 below by program areas.

Table 3. Doctoral Student Mean Scores of Entrepreneurial Constructs by Area

Construct	Business Doctoral Students (n=8)		Computing Doctoral Students (n=10)		Engineering Doctoral Students (n=14)	
	Mean	SD	Mean	SD	Mean	SD
Self-Efficacy	5.52	0.66	5.53	0.60	5.31	0.78
Entrepreneurial Efficacy	5.03	0.91	5.14	0.79	5.31	0.51
Tinkering	4.31	1.24	4.14	1.43	4.59	1.20
Design	4.65	0.74	4.98	0.94	5.21	0.62
Creativity	5.35	0.36	4.73	1.07	5.05	0.56
Teamwork	5.75	0.39	4.69	0.99	4.96	0.80
Innovation	5.29	0.34	4.52	1.13	5.08	0.52
Network	5.48	0.46	4.48	1.22	4.85	0.83

An analysis of variance was performed on the eight constructs by the three doctoral areas of Business, Computing and Engineering. No statistically significant differences were found. We interpret this as an indication of similarity among doctoral students in attitudes toward entrepreneurship.

Discussion

The PAtENT innovation is threefold. The development of a new doctoral pathway for entrepreneurship provides an alternate roadmap for Doctoral candidates to satisfy their capstone degree requirements through the development of patentable technology. The pathway activities have the potential to replace the current standard practice of publication in peer-reviewed journals typically employed at R1 and R2 institutions with applied technology research and development. The structural innovation is achieved without sacrificing the technical rigor of the program or the external peer-reviewed component, thereby ensuring adaptability to a range of academic cultures. Second, original pedagogical hypotheses relating to the modifications to student experiential learning, self-perception, and learning outcomes are being formulated and tested across four different programs in the STEM fields. Finally, the study of the PAtENT roadmap is expected to generate tools and recommendations necessary for other STEM doctoral programs to make informed decisions as to the adoption of the pathway model.

The PAtENT model provides a framework for a fundamental reimagining of the STEM doctorate from being largely a traineeship for academic careers to one that could lead to higher rates of technology entrepreneurship. A wider adoption of the PAtENT model will significantly impact the STEM workforce in the US, preparing graduates for the emerging knowledge economy. At scale, the corresponding increase in technology startups, intellectual property, and downstream employment will vitalize regional and national economies, while extending the nation's leadership in science and technology. Findings generated from our study will be shared to focus on best practices for a diverse student body in doctoral education, that are designed to serve as a pipeline for technology entrepreneurship. PAtENT is laying the groundwork for a wider debate on the evolving role of modern STEM doctoral programs, and opening the door for other innovations to the Ph.D. roadmap that better prepares students for entrepreneurial innovation careers.

Conclusion

The PAtENT modal for doctoral education seeks to expand the graduate education ecosystem to include student-centered approaches that catalyze research entrepreneurship. This new pathway to Ph.D. provides a roadmap for modernizing STEM doctoral programs so that they align with the rapidly expanding employment landscape. The model is student-centered because it allows a wider variety of options to degree, without extending curricular requirements. We anticipate that findings from our research, evaluation and assessment will provide proof of concept for other doctoral programs to replicate and scale Doctor of Innovation tracks.

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