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Pathways to Entrepreneurship (PAtENT): Addressing the National Academies Recommendations

Dr. David K. Pugalee, University of North Carolina at Charlotte

Dr. David Pugalee is a full professor, and Director of the Center for Science, Technology, Engineering, and Mathematics Education (STEM) at UNC Charlotte. The recipient of millions of dollars in grant-funding, Dr. Pugalee has also published works on STEM teaching and learning.

Praveen Ramaprabhu

Praveen Ramaprabhu is a Professor of Mechanical Engineering & Engineering Sciences at UNC Charlotte, where he heads the Laboratory for Multiscale Computational Fluid Dynamics (LMCFD). Starting with his Ph.D. research at Texas A&M University, Dr. R

Dr. Mesbah Uddin, University of North Carolina at Charlotte

Dr. Mesbah Uddin is a Professor of Mechanical Engineering and Engineering Science at the University of North Carolina at Charlotte's Williams States Lee College of Engineering. He is currently leading Charlotte's new multidisciplinary public-private research partnership initiative, Digital Design and Optimization (DDO), which is intended to strengthen Charlotte's connections to North Carolina defense and security-related companies interested in multidisciplinary advanced manufacturing, engineering design and optimization, computer science and cybersecurity, and manufacturing innovation. He is currently serving as the Chair of the Society of Automotive Engineers (SAE) Road Vehicle Aerodynamics Forum Committee, a committee responsible for developing and maintaining SAE standards, technical papers, and special publications related to road vehicle aerodynamics and wind noise performance and test techniques. He is a member of UNC Charlotte Military Affairs Committee. In addition to the SAE International, he is an active member of various professional societies, such as the American Institute of Aeronautics and Astronautics (AIAA), American Society of Mechanical Engineers (ASME), American Society for Engineering Education (ASEE), and American Physical Society. He is a member of the AIAA Turbulence Model Benchmarking Working Group. In the past, he served as: the Director of North Carolina Motorsports and Automotive Research Center during 2012-22, a member of North Carolina Governor's Motorsports Advisory Council during 2012- 2017, and a senior CFD analyst at the then Chrysler's in its NASCAR, NHRA, street and passenger car computational aerothermal development programs. At present, Dr.Uddin's group focuses on the improvement of the aerothermal predictive capabilities of virtual and physical systems using machine learning and reduced order methods

Dr. H. P. Cherukuri, University of North Carolina at Charlotte

Harish Cherukuri is the Chair and Professor of Mechanical Engineering and Engineering Science at UNC Charlotte. Dr. Cherukuri obtained his Ph.D. from the Department of Theoretical and Applied Mechanics, The University of Illinois at Urbana-Champaign. His

Prof. Terry Xu, University of North Carolina at Charlotte

Dr. Terry Xu is a professor in the Department of Mechanical Engineering and Engineering Science at the University of North Carolina at Charlotte. She currently serves as the Associate Chair for Graduate Programs. Her research interest is in the field of

Audrey Rorrer

Audrey Rorrer, PhD, is a Research Associate Professor in the Computer Science Department at UNC Charlotte, where she also serves as Assistant Director of the Center for Education Innovation & Research. Dr. Rorrer's scholarship areas include the science of broadening participation in computing, SoBP, which is a recognized domain of critical importance in STEM workforce development and educational programming. Her work has focused on educational programs, outreach and collective impact activities that expand the national pipeline into STEM careers. College student development and Faculty career development are central themes across her body of work.

Pathways to Entrepreneurship (PAtENT): Addressing the National Academies Recommendations

Abstract

Though the field of engineering has experienced significant changes over the last several decades, many graduate programs have not made any substantive changes in their curriculum. This is particularly important given that data show that over sixty percent of new doctorate program graduates do not go into academic research [1]. Recognizing the critical need for change, the National Academies of Sciences, Engineering, and Medicine [2] made recommendations for graduate STEM education programs. The intent was to examine how graduate STEM education can focus on evidence-based practices which better respond to the needs of students and broader society. The Committee on Revitalizing Graduate STEM Education identified key competencies for educational systems so that they are dynamic in addressing current needs of students while anticipating future contexts in STEM graduate education. These competencies were the framework for this research which employed curriculum analysis methods to the PAtENT (Pathways to Entrepreneurship), an alternate pathway to the doctorate in engineering at this University. The curriculum analysis included the two components of the Academies' recommendations: 1) Develop scientific and technological literacy and conduct original research and 2) Develop leadership, communication, and professional competencies. The research used a dimensional core curriculum analysis [3 - 4] to analyze program information including documents, artifacts, and other data related to coursework, original research, student classroom experiences as well as laboratories and fieldwork. The descriptive content analysis used a systematic process to allow for identifying attributes within documents and data in order to align identified components to program activities and structures. Coding for the curriculum analysis used an inductive, thematic and descriptive approach in aligning program components and activities to ten elements listed for the two components in the Academies' recommendations. Document analysis identified curriculum expectations and program outcomes that were tagged to the elements in the recommendations. The goal of this research was to identify PAtENT program activities and features that best addressed a particular element. Procedures followed key processes from curriculum study methodology including identifying desired outcomes, determining what content and activities contributed to those outcomes, and identifying experiences developed to result in those intended outcomes [5 - 7]. This systematic process identified attributes and components of PAtENT program features that aligned to the ten elements.

Description of the PAtENT Program

The Pathways to Entrepreneurship (PAtENT) model was developed to provide advanced engineering students at this university an opportunity to develop a broader range of entrepreneurial and research design skills. This is especially critical since data indicate that only about 10% of doctoral STEM graduates go into tenure-track positions. Workforce estimates show that only 10% of doctoral graduates in STEM overall obtain tenure-track positions [8] with most going into the private sector. These private and business positions require a range of skills and knowledge including leadership, communication, and teamwork [9] as well as an in-depth understanding of business, social, and ethical contexts [10]. The PAtENT model responds to these challenges through a curriculum focused on building these skills and providing such connections throughout the academic experience of the doctoral student and not as an add on to a traditional program. The program was implemented at one university with the intent that this model was adaptable to other institutions.

The PAtENT model applies a student-centric approach to focus the educational emphasis toward the development of entrepreneurial skills necessary to engage in the modern and rapidly changing technical workforce. A flexible, alternative pathway is offered instead of the traditional graduate program, that does not add time to completion nor reduce technical rigor. The model design adheres to the core elements identified as essential for doctoral education, which are to develop scientific and technical literacy, leadership, communication, and professional competence, and catalyze original research [2]. Students, and their faculty advisors, who choose the alternative pathway, are able to select a commercial idea/patent proposal in lieu of the traditional dissertation proposal. They then proceed with their original research, submitting a patent application, and defending the proposal submission. The PAtENT program has three goals: (i) to develop an alternate roadmap for STEM Ph.D. students that is scalable and reflective of the evolving employment landscape and workforce needs; (ii) to study the pedagogical implications of these innovations, and to develop original pedagogical research; (iii) to develop strategies to broaden participation.

A primary approach of the program is an emphasis on the development of a range of skills required to compete in the rapidly changing and modern knowledge economy, without compromising the technical rigor or the original intent of the engineering doctorate. Alternatives to current Ph.D. roadmaps should ensure that the core elements identified as essential to all STEM Ph.D. education programs in the NAS report from its Call for Community Input [2] are delivered through program requirements. These core elements are "(i) Develop scientific and technological literacy and conduct original research and (ii) Develop leadership, communication, and professional competencies". PAtENT provides an innovative alternative to the current roadmap, a novel pilot program that ensures the core elements of STEM doctoral education are delivered, while satisfying the multiple requirements and needs described above that address changing workforce needs. Figure 1 compares the proposed roadmap with the current doctoral program in engineering.

One central feature of this program is an emphasis on entrepreneurship. Research on doctoral programs with an entrepreneurial emphasis are very limited but early results from programs with a training and internship focus have shown early promising results [9]. The PAtENT program differs from these other offerings by providing an alternative pathway to develop knowledge and skills in entrepreneurship and technology development while maintaining the total academic load and technical rigor. Thus, the program is a philosophical paradigm shift in the STEM Ph.D. model, where rigorous scientific research can (and is often necessary to) pave the way for commercialization of a technology.

This alternate pathway 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) and based on the direction of their research and potential for development of a patentable technology, the student will have an option to pursue the alternative pathway. The research topic proposal will be replaced with a defense of the patent proposal where satisfaction in meeting this requirement is based on input from the dissertation committee as well as the university's patent review committee. The student will then prepare a patent application, which will be externally peer-reviewed by a committee of research scientists and technology entrepreneurs, appointed by the university patent committee. Based on feedback from this external review committee, the student will submit a patent application, which will form the basis for the student's written dissertation and final defense. The final defense in the current Ph.D. roadmap is the traditional dissertation defense with the final defense of the dissertation being the end product. In the alternate pathway, the final defense and written dissertation is based on the successful patent application. The dissertation provides the student a professional forum based on their patent proposal. The dissertation serves as a broader presentation of the work done for the patent application process. Should feedback from the external review committee be negative, students consult with their dissertation committee on an appropriate path forward including (i) resubmission after modifications for external review, (ii) submitting the results for publication in a journal and reverting to the traditional track, or (iii) directly proceeding to produce a written dissertation. While there are no special designations on the diploma, program information is available on the university's website. Graduates who have patent work on their vitas will draw attention to the nature of th graduate program.

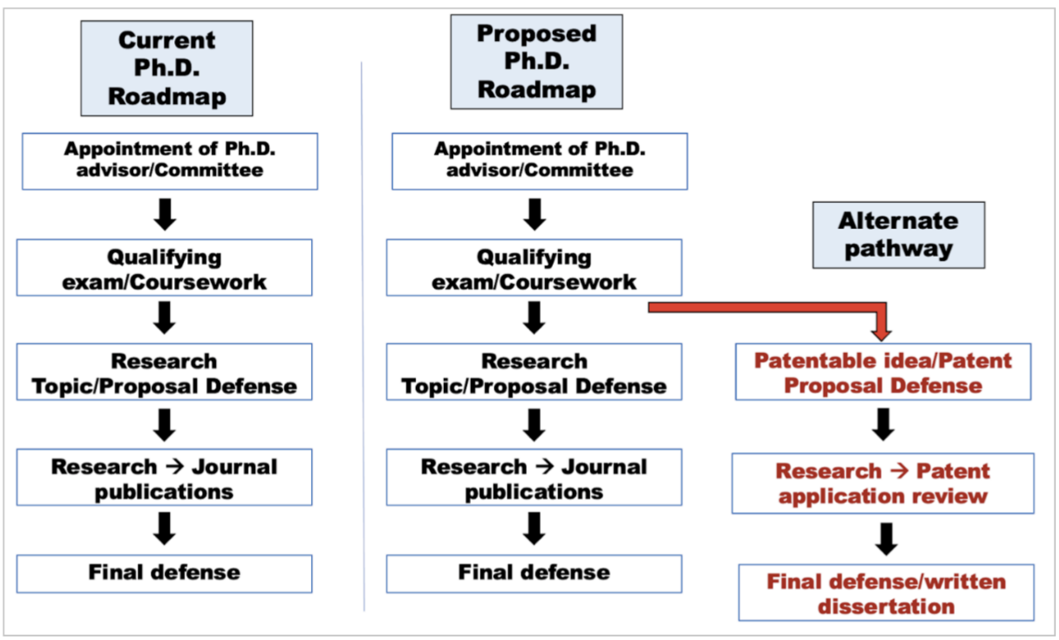

Figure 1: Current and proposed Ph.D. Roadmaps

Curriculum Study of the PAtENT Program

PAtENT addresses limitations in engineering doctoral programs of study. The program sought to respond to recommendations from the National Academies of Sciences, Engineering, and Medicine [2]. Researching curriculum is a vital step in demonstrating that curriculum has coherence and relevance in addressing the needs of learners, in this case articulated through the recommendations of the National Academies. Curriculum research is necessary to drive curricular reform in engineering and prioritizing activities to reach desired outcomes [11]. The following research question drove this study:

> How do program components address the core recommendations for STEM doctoral programs from the National Academies of Sciences, Engineering and Medicine:
>
> A. Develop Scientific and Technological Literacy and Conduct Original Research?
>
> B. Develop Leadership, Communication, and Professional Competencies?

Methods

This research employed a dimensional core curriculum analysis to determine how program components from this one university's experiences aligned to the Academy's recommended elements [3] [12 - 14]. This analysis is critical in showing support for the program as a model for other STEM doctoral programs. In this analysis, the core elements and their related components were used to describe the knowledge and skills as critical outcomes of the program. This involved compiling a matrix for collecting analytical information about the curriculum components, how they are implemented and assessed across the program, and student outcomes. This research also employed several approaches in the analysis: focus group interviews, structured and semi-structured student interviews, performance assessments, observations, tests and other assessments, document analysis, and questionnaires from both candidates and faculty. Initial Interviews with four students and two faculty members were semi-structured and supported triangulation of data across the multiple sources used as part of the curriculum analysis. This analytical process sought to provide clarity and comprehensibility, thus allowing for a systematic examination of the program's success in addressing the elements and their related Academy components and the potential of this program as a model which could provide a basis for redesigning STEM doctoral degree programs.

Findings

The Academy recommendations included two core elements: the development of scientific and technological literacy and conduct of original research; and the development of leadership, communication, and professional competencies [2, pp. 106-107]. Figure 2 identifies program competencies and components based on the analysis. The visual breaks the first element into two parts to better convey key findings (Develop Scientific and Technological Literacy, Conduct Original Research).

The curriculum mapping study identified the experiences (i.e. the actual curriculum) in comparison with the core elements of quality STEM education Ph.D. programs from the National Academies study [2]. Current highlights of the curriculum mapping include specific program components mapped to each of the core elements. Mapping allows identification of those educational experiences that are purposefully and logically structured in a way that shows mapping or alignment to the elements of the recommendations. Table 1 provides a summary of key program activities that were identified through the curriculum analysis for each of the 10 elements within two components.

Discussion

The first component addresses the development of scientific and technological literacy and conducting original research. The alignment study supported program requirements which retain the emphasis on specialized knowledge in engineering. The PAtENT program trajectory (see Figure 1) highlights the importance of the degree capstone requirements through the development of patentable technology and the submission of a (peer-reviewed) patent application [15]. Candidates are mentored through their Ph.D. committee and complete a subject matter comprehensive exam, preserving a strong emphasis on the development of specialized knowledge and skills. Patent planning is a 4-step process: understanding the invention, researching the invention, choosing the type of protection, and drafting the patent application. This provides a core program requirement which addresses recommendations around identifying and researching a problem, developing a research strategy, and evaluating outcomes. The requirement to develop a viable patentable technology, reviewed by the patent committee and the external peer review of the proposed technology, reinforces the program's emphasis on technological literacy. Candidates must conduct research and develop a plan to support a patent proposal. Satisfaction of this requirement will be based on input from the student's Ph.D. committee as well as the University's patent review committee. The next step is completing a patent application, which will be externally peer-reviewed by a committee of research scientists and technology entrepreneurs (appointed by the University's patent committee). One program completer in nanoscale science highlighted this experience:

> We still published, but in the process, we got three patents submitted to the university, and one is currently at the US Patents Office, so that was really cool. A lot of people liked this aspect whenever I talked about it in my defense… Everybody really wants to get patents done, and people are always really excited about trying to get this to commercialization.

Students continue to pursue publications of their work, though the primary focus is on the patent as their capstone experience. As the feedback from one completer (above) suggests, students may be involved in more than one research project with more than one leading to patent proposals.

Additionally, candidates have specific opportunities to develop entrepreneurial skills such as enrollment in courses offered by the College of Business with a focus on entrepreneurship and innovation including Entrepreneurial Decisions, Entrepreneurial Strategy, Innovation Analytics, Evaluating Entrepreneurial Opportunities, Entrepreneurial Organizing, Entrepreneurship and Uncertainty, and Corporate Entrepreneurship. Candidates also participate in a six-week boot camp on entrepreneurship training developed by Ventureprise, the University's NSF I-Corps site. Candidates also learn professional norms and practices, including specific graduate school requirements as they complete two courses focusing on academic integrity and the responsible conduct of research. Candidates engage in interdisciplinary work as supported in interviews:

> We have collaborations. Well, right now, the biggest collaboration is over in the optics and physics department. So they are doing some measurements for us, and they are actually finding some really cool stuff. We are also trying to collaborate within the chemistry department and … reach out to some bio people.

The second component is developing leadership, communication, and professional competencies. Leadership is a major thrust of the management electives and the possible pathway to a certificate in Entrepreneurship and Innovation. All candidates are required to take at least one management course to build leadership skills. Students also have the option to complete 9 additional hours to meet requirements for the graduate certificate program in Entrepreneurship and Innovation through the College of Business. These courses develop skill sets related to the different aspects of entrepreneurship and innovation. The graduate certificate requires two core courses - Innovation and Change Strategy and Business Models and Business Plans and two electives. One candidate noted, “I sat in on the entrepreneurial decisions class, which got me thinking about different [topics] other qualifications.” Another element is developing communication skills. Communication is an important skill targeted through the NSF I-Corps program which organizes professional development opportunities for entrepreneurs and mentoring by commercialization experts. These opportunities broaden candidates’ communication skills development to include academics and professionals. A candidate, who also served as a teaching assistant, notes “I would say Ventureprise … definitely helped with trying to figure out how do you communicate with people outside of the university, and how do you get people’s attention, and get them to talk to you?” Continuing, he noted that there were opportunities to do presentations through attending conferences and this helped get better with professional communication. An additional area is the development of professional skills. As already noted, entrepreneurship opportunities target technology-specific strategies and case studies, customer discovery, decision making, financing, team management, and product development. Candidates noted involvement with the Graduate & Professional Student Government which serves as the primary representative body of graduate and professional students at the University, with several candidates noting travel support for professional conferences. Also noted were specific professional societies such as the American Chemical Society, the Society of Women Engineers, and the American Society of Mechanical Engineers. These professional competencies are clearly conveyed in comments from candidates such as “Most shifted thinking. The shift in thinking is going from all academic research, small lab-scale things to thinking about, okay, how do we scale this bigger.” This level of Professionalization links explicitly to the recommendations which were the focus of this study.

Competency	Program Components
Develop Scientific and Technological Literacy	• Required to enroll in two courses offered by College of Business on Entrepreneurship and Innovation, such as Entrepreneurial Decisions
Conduct original research	• Student presents research idea to Committee • If Passed, student presents to full Patent Committee • If Approved, a provisional patent application is submitted • Student drafts the technical description of the full patent application
Develop leadership, communication, & professional competencies	• Required to enroll in Graduate Business courses • Or participate in Venturprise training modules

Figure 2. Curriculum Mapping of Program Components to National Academies Core Educational Elements

Table 1. National Academies STEM Education Recommendations and PAtENT Key Activities [Authors]

1. Develop Scientific and Technological Literacy and Conduct Original Research	
a. Develop deep specialized expertise in at least one STEM discipline.	Progress in program requires acquiring deep specialized expertise and conducting original research; also emphasizes entrepreneurship.
b. Acquire sufficient transdisciplinary literacy to suggest multiple conceptual and methodological approaches to a complex problem.	Required to enroll in courses offered by College of Business on entrepreneurship and Innovation, in addition to engineering program.
c. Identify an important problem and articulate an original research question.	Patent planning which has a 4-step process.
d. Design a research strategy, including relevant quantitative, analytical, or theoretical approaches, to explore components of the problem and begin to address the question.	Committee evaluates the student's progress towards the research goals as outlined in the proposal for research.
e. Evaluate outcomes of each experiment or study component and select which outcomes to pursue and how to do so through an iterative process.	Support for progress toward filing a provisional patent, overseen by the entire committee, and supervised by faculty mentor.
f. 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.	Viability of the patentable technology (as determined by the patent committee), and external peer review of the proposed technology.
g. Learn and apply professional norms and practices of the scientific or engineering enterprise, the ethical responsibilities of scientists and engineers within the profession and in relationship to the rest of society, as well as ethical standards that will lead to principled character and conduct.	Two required courses focusing on academic integrity and responsible conduct of research.
2. Develop Leadership, Communication, and Professional Competencies	
a. Develop the ability to work in collaborative and team settings involving colleagues with expertise in other disciplines and from diverse cultural and disciplinary backgrounds.	Management electives can lead to graduate certificate in Entrepreneurship and Innovation; candidates are required to take at least one management course.
b. Acquire the capacity to communicate, both orally and in written form, the significance and impact of a study or a body of work to all STEM professionals, other sectors that may utilize the results, and the public at large.	Students participate in Ventureprise (NSF I-Corps site) on-campus training modules and professional development programs for aspiring entrepreneurs, mentoring by commercialization experts, customer discovery.
c. Develop professional competencies, such as interpersonal communication, budgeting, project management, or pedagogical skills that are needed to plan and implement research projects.	Entrepreneurship 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.

Conclusions and Next Steps

This curriculum study demonstrates how the Pathways to Entrepreneurship (PAtENT) Program responds to the National Academies [2] views on the nature of the STEM doctorate for the 21st century. The findings show one model for doctoral engineering study that is responsive to the changing landscape for graduate education. The experiences at this one institution can serve as a model for other institutions seeking to revise their graduate STEM programs.

> The education and training that students receive during their Ph.D. education should provide them with the ability to conduct original scientific research. The core education elements would establish a STEM Ph.D. educational mission, with alignment across the key components of the degree program … That mission establishes a Ph.D. education as one that would 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." pp. 95-96

The alignment to the core elements provides a framework for programs as they design learning opportunities in graduate STEM education designed to prepare candidates so they can effectively respond to modern day problems and challenges - a critical goal for graduate STEM education.

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