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Faculty and Students' Perceptions and Experiences in the STEM Patent Pathway Program and Entrepreneurial Mindset Development: A Case Study

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Abstract

In recent years, graduate programs in Science, Technology, Engineering, and Mathematics (STEM) have been increasingly challenged to evaluate how effectively they prepare students for diverse career trajectories and workforce demands. Some universities have begun developing innovative doctoral programs that explore alternative defense pathways beyond the traditional dissertation model. One such initiative is the Pathway to Entrepreneurship Patent Program, which offers a creative, student-centered framework within graduate education [1]. The purpose of this study is to investigate doctoral students' and faculty's experiences and perceptions with a pilot patent defense program in engineering disciplines. Despite growing interest, there is limited research on an alternative patent proposal defense for engineering doctoral students. Most doctoral programs remain focused on conventional academic research and are often less aligned with applied science and workforce needs. Furthermore, such programs overlook essential industry-relevant skills such as leadership, communication, and teamwork abilities, which are vital for success beyond academia [2]. Establishing an entrepreneurial mindset and socialization can equip students with comprehensive skills to work effectively in industry, government, and business [3]. The pilot patent proposal defense, compared to the conventional research proposal defense, provides doctoral candidates with practical experiences that develop their entrepreneurship [1]. This qualitative case study employs thematic analysis of interview transcripts guided by an entrepreneurial mindset theoretical framework [4]. The participants include one current Ph.D. student, three alumni, and five faculty members from mechanical engineering, chemistry, and optical science. In conclusion, students' and faculty's interviews provide valuable insight into the perceived beliefs of the patent pathway program. The findings suggest that an innovative alternative patent defense can foster engineering doctoral students' entrepreneurial awareness. The entrepreneurial mindset significantly contributes to students' professional competencies, positioning them as well-rounded candidates in both academic and broader employment contexts.

Keywords: Entrepreneurial Mindset, Entrepreneurial Awareness, Entrepreneurship, Patent, Patent Pathway, Intellectual Property, STEM Education, Engineering Education, Graduate Education, Higher Education

Introduction

Entrepreneurial Mindset (EM) was regarded as an essential benefit for engineering students. An entrepreneurial mindset is a cognitive behavior to inspire an engineer toward opportunity realization and value innovation under a specific context, as well as to initiate the orientation of an entrepreneurial venture [5]. An entrepreneurial mindset was particularly applied to engineering doctoral students because they embraced more senior knowledge and skills and could develop intellectual properties. Moreover, Entrepreneurial Minded Learning (EML) is an instructional approach that equips students with the skills to recognize opportunities, prioritize meaningful impact, and generate value through their solutions [6]. The entrepreneurial mindset is rooted in three fundamental components: curiosity, connections, and value creation [6]. Entrepreneurial education shapes university students' entrepreneurial intention and self-efficacy [6] [7]. It is implied that the entrepreneurial education programs cultivate students' entrepreneurship awareness apart from the mathematics theory, equations, calculation, or experiment, which are from the traditional STEM education program.

Intellectual capital and innovation were elements that enabled universities to achieve the goal of knowledge transfer [8]. According to a study from ten European countries, the higher education system contributed to two entrepreneurial-related developments in the 21st century: 1) for research, to improve scientific knowledge that can progress technological innovation; 2) for the community, to foster the connection between research and business such as patent, incubation, and venture [9]. Entrepreneurship in higher education is playing a crucial role in linking academic research and potential business. Although some studies have investigated entrepreneurship efficiency by designing engineering courses [10] [11] and evaluating entrepreneurial activities [6] [12], there was a lack of studies focusing on the entrepreneurial patent pathway program in doctoral education. The purpose of this case study is to understand the perceptions and experiences of doctoral students and faculty regarding how the alternative patent defense pilot program in STEM disciplines influences an individual's entrepreneurial mindset and contributes to the sustainable development of graduate education. To address research gaps, three research questions are presented as follows:

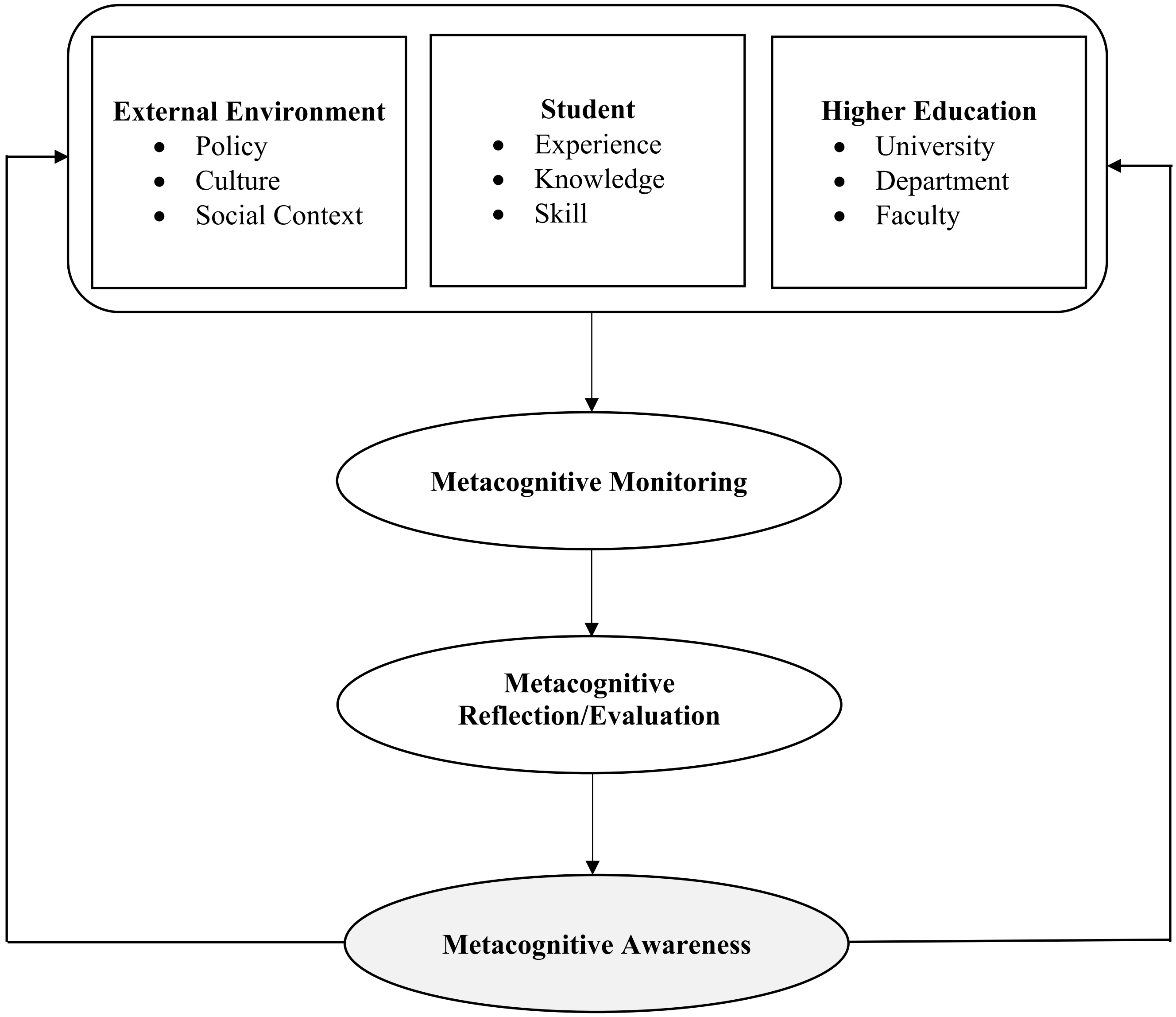
1. What are the perceptions and experiences of students and faculty in the patent entrepreneurial pathway program?
2. What influential education outcomes do students achieve in the patent entrepreneurial pathway program?
3. What aspects of the entrepreneurial mindset do students and faculty perceive in the patent entrepreneurial pathway program?

Theoretical framework

Entrepreneurial mindset

The Entrepreneurial Mindset (EM) was regarded as a cycle of cognitive thinking, behavioral acting, and emotional feeling aspects [13]. An EM could be nurtured by entrepreneurial education to enhance the university students' entrepreneurial self-efficacy, entrepreneurial intention, and the likelihood of being a start-up [14], [8]. Graduate students were encouraged to cultivate an entrepreneurial mindset in problem-solving skills, life-long learning, and scientific creativity. The EM STEM class activities consisted of innovation and perseverance cultivation, so students were able to exhibit entrepreneurship involvement from the designed curricula [5]. Entrepreneurial-Minded Learning (EML) was an educational approach that equipped students with the skills to recognize possibilities, prioritize making a difference, and generate worth through their innovations [6]. Haynie et al. introduced an entrepreneurial mindset model from social and cognitive psychology, emphasizing that entrepreneurial metacognition is rooted in the external environment, metacognitive awareness, metacognitive knowledge and experience, metacognitive strategies, and metacognitive monitoring [15]. This model highlighted how entrepreneurs develop a "higher-order" cognitive process in nature to navigate and succeed in their entrepreneurial pursuits. This study adjusted Haynie et al.'s entrepreneurial metacognition model to build the conceptual model (Figure 1). The model demonstrated how students' entrepreneurial metacognition awareness developed through the metacognitive monitoring and metacognitive reflection processing (Figure 1).

Figure 1
Adjusted entrepreneurial mindset metacognition model



Literature review

Engineering pathway education

Pathways have varied definitions in the education area. For example, the pathway can be a two-semester intellectual property protection course for biomedical students [4], STEM major students' two-year institutions and entry-level work [16], or post-PhD early career management training for women's leadership role [17]. The pathway context in this study is referred to as an alternative Ph.D defense program. Instead, the traditional doctoral graduation roadmap is constructed by qualifying exams, coursework, journal publications, and dissertation defense. An innovative defense pathway is designed to demonstrate a patentable proposal, submit a patent application, and anticipate patent property as the final dissertation [1].

Engineering pathway education and entrepreneurial mindset

The incentive policies for rewarding entrepreneurship activities and patent contributions had a positive relationship between students and faculty. An increasing number of innovations and knowledge transfer graduate programs can encourage higher education institutions' technological culture change [6]. Pathway education composites the idea of patent development, productivity efficiency, customer discovery, marketing discovery, sales strategy, technology transfer, and venture planning. With the knowledge of attributes, the lab-to-market outcomes enable graduate students to accomplish deliberate entrepreneurial expertise [18]. Universities supported academic entrepreneurship, also known as their 'third mission', by providing various facilitative mechanisms, i.e., science and technology parks, incubators, and entrepreneurship initiatives [19].

The entrepreneur pathway advocates a patent defense for doctoral students, encouraging students to change their mindset from traditional defense practice to pursuing patentable property. Meanwhile, universities promote the entrepreneurship culture and activities to accelerate the ownership mission accommodation. Nevertheless, a research gap exists in defining a patent entrepreneurship model that enables universities to transition from traditional research-oriented frameworks to ones that systematically incorporate intellectual property. This study will uncover doctoral students' experiences in developing an entrepreneurial mindset, as well as professors' evaluative perspectives on the pathway defense program.

The present study

The patent pathway program is a pilot project developed by a state university in the Southeastern U.S. It is a three-year National Science Foundation (NSF) funded program targeted to doctoral candidates. Students in the program can receive $5000 per academic year, and they are allowed to use the funding to attend conferences and purchase equipment. Meanwhile, a student can register for an entrepreneurial course, which is either the "Entrepreneurial Decision" or an entrepreneurial workshop held by the business school. Even though the program serves students, the program is based on mutual agreement between students and their advisors. If either faculty or student does not agree to participate in the project, they are not eligible to join the program. With respect to learning outcomes, it is anticipated that doctoral candidates in the pilot program can submit the patent as the final defense instead of the conventional paper defense to meet the requirement of graduation so that students can achieve the doctoral degree. The role of the faculty is to provide academic and technological support for students to complete the patent filing. Since the project is a pilot trial, there is no requirement for the candidate to develop a patentable product at the end.

Methods

Research design

This study adopts a qualitative case study to examine university STEM students' and faculty members' perceptions and experiences of the patent pathway program. A case study is an empirical inquiry that investigates a contemporary phenomenon within a real-life context [20]. The case study is a design of inquiry, in which the researcher develops an in-depth analysis of a case, a program, or one or more individuals over a sustained period [21]. Methodologically, this study employed a holistic single-case design, in which the patent pilot program was a case. The case study helps researchers investigate the educational effect of the patent program and entrepreneurial mindset development.

Participant description

Participants in the study were from a state university in the Southeastern U.S. The sampling method was a purposive selection. It is suggested that the sample size depends on the qualitative approach, and the case study includes about four to five cases [21]. Demographically, the researcher invited the students and their academic advisors. There were a total of nine participants recruited: five faculty members (Table 1), three alumni, and one student (Table 2). Alumni's patentable experiences were based on their retrospective perspectives when they studied at the university. For confidential consideration, all participants' authentic names will be the alphabet to refer to. The faculty member used the capital letter (i.e., A), and their student used the capital letter and Arabic number (i.e., A-1), representing the advisor-student relationship. Particularly, faculty C's student was not included in the study because his student could not complete the interview.

Participants' data were collected from June to August in 2024. The researcher sent out the interview invitation email and attached the informed consent form. Before approaching participants, the project received approval from an Institutional Review Board (IRB) at the university. Participants took part in the research voluntarily. The inclusion criteria for the participants were that the student studied and faculty worked: 1) in the university; 2) in the STEM field; 3) at the doctoral level; 4) in the pilot patent program for at least one year.

Table 1

Characteristics of faculty member participants

Participant	Gender	Profession	Administration	Department	Full Patent Experience	Startup Experience
A	Female	Full Professor	Associate Chair of Graduate Program	Mechanical Engineering	No	No
B	Male	Full Professor	N/A	Mechanical Engineering	Yes	Yes
C	Male	Assistant Professor	N/A	Mechanical Engineering	Yes	No
D	Male	Full Professor	Director of Graduate Program	Chemistry	Yes	Yes

E	Male	Associate Professor	Director of Graduate Program	Optical Science	Yes	No

Table 2
Characteristics of student and alumni participants

Participant	Gender	Graduation Year	Career	Department	Year of Program Participation	Full Patent Number	International Student
A-1	Female	N/A (Second-year Ph.D. Student)	N/A	Mechanical Engineering	1	0	No
B-1	Female	2022	Industry	Mechanical Engineering	1	0	Yes
D-1	Male	2023	Post-Doc Entrepreneur	Chemistry (nanoscale science)	2	3	No
E-1	Female	2024	Government	Optical Science	2	0	No

Data collection
The research conducted an in-depth one-to-one interview through the virtual Zoom setting. The interviewer was the researcher, who was a doctoral student from the education department. The interview was designed for 30 minutes. Finally, each informative interview lasted about 60 minutes. The interview involved a semi-structured interview protocol that contained seven questions. All interview questions were prepared before the interview and were applied to every participant consistently. The researcher asked some follow-up questions according to the context understanding. The advantage of an interview is that it enables the researcher to control the line of questioning [21]. Each interview was recorded by Zoom software, and Microsoft Dictate and Google document voice typing functions were employed for data collection. The researcher took notes during the interview and saved the notes along with the audio data in a secure computer folder.

Data analysis procedure
The data analysis referred to the theoretical framework of the metacognitive model of the entrepreneurial mindset [22], which explained the entrepreneurial metacognition development from entrepreneurial environment, individual experience and knowledge, and metacognitive monitoring. The researchers developed five initial themes according to the adjusted conceptual framework (Figure 1), which consisted of the external environment, student experience and knowledge, higher education, metacognitive awareness, and metacognitive evaluation. Our

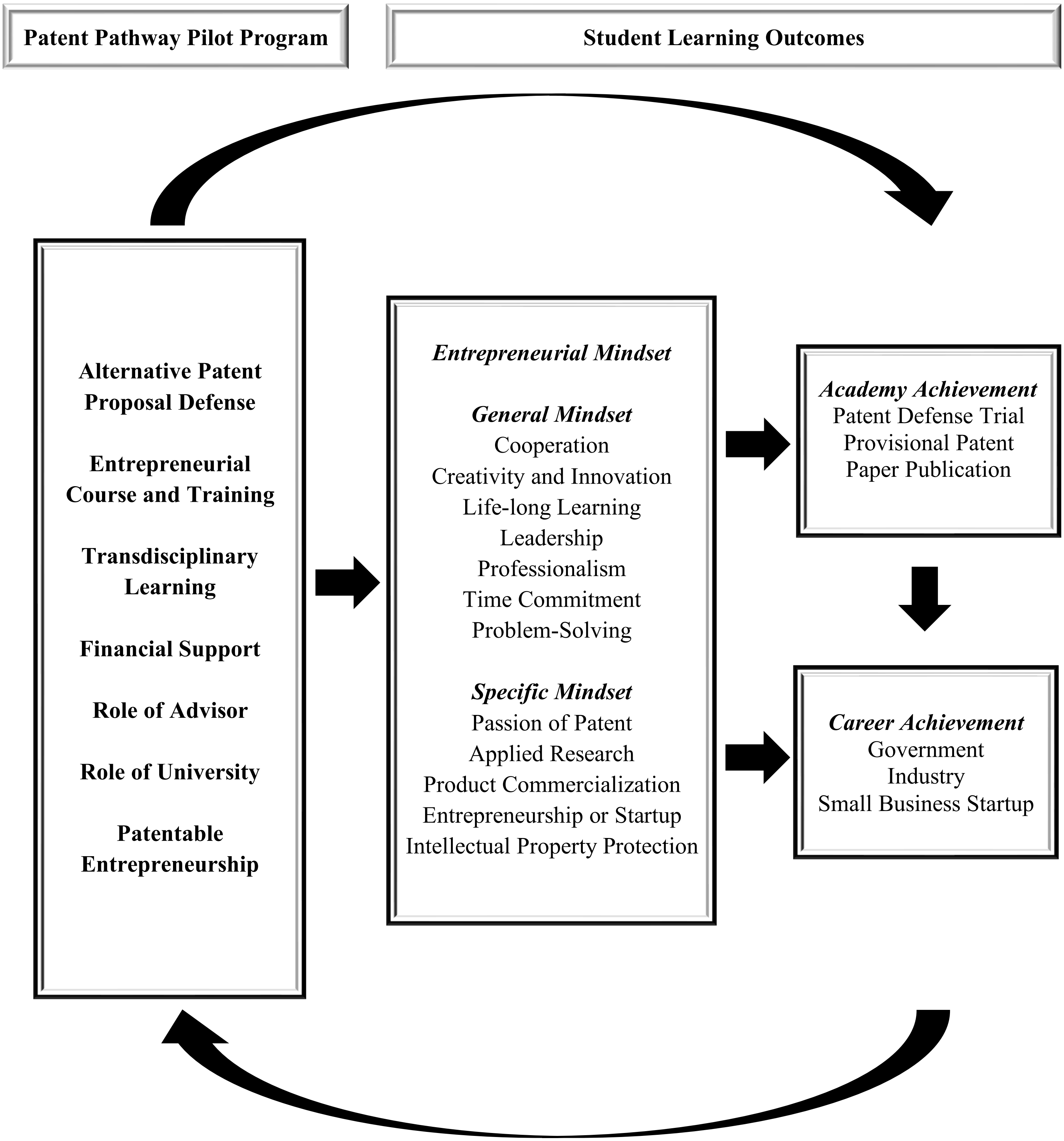
model illuminated how entrepreneurs cultivate "higher-order" metacognitive strategies and entrepreneurial awareness in the pursuit of a patent defense program.

Data analysis aims to decode the text and interpret the meaning of the transcripts. The process embraces data segmenting and replacing [21]. Firstly, the audio data employed a verbatim strategy assisted by the Microsoft dictating function. The transcripts were screened to check the grammar, punctuation, paragraph, and meaning. Raw data were organized in a Microsoft Word document before analysis. Secondly, the researcher read the transcripts twice before analysis to reflect their overall meaning and the ideas of participants. For example, identifying the tone of expression (i.e., you know), repetitive emphasis (i.e., it is so important, so important), and extra questions and answers were essential for data interpretation. Furthermore, this data was adopted for inductive thematic analysis using open coding. The data were coded by NVIVO 15 software. The researcher organized the coding by bracketing chunks to represent different sub-codes based on the five themes derived from the conceptual framework (Figure 1).

Findings

The qualitative findings were derived from faculty and students' program reflection and entrepreneurial awareness after they participated in the pilot patent defense program. The thematic analysis results demonstrated an individual's patent experience, entrepreneurial mindset development, and learning achievement cycle (Figure 2). Students' academic and career achievements provided strong evidence that the alternative patent defense program positively cultivated individuals' general and specific entrepreneurial mindset, providing insightful evidence on the success of the patent pathway program. A descriptive analysis of the thematic coding of the patent entrepreneurial pathway program (Table 3), education outcomes (Table 4), and the entrepreneurial mindset (Table 5) was attached to the representative findings.

Figure 2
Overview of thematic analysis findings of entrepreneurial mindset development in the patent pathway program



Research question 1: What are the perceptions and experiences of students and faculty in the patent entrepreneurial pathway program?

1. Patent pathway pilot program: An innovative education pilot program for STEM doctoral students

1.1 The significant pedagogy effect of the patent pathway program

All four students and five faculty members highly appreciated the patent pathway pilot program, noting its transformative impact on graduate education compared to traditional paper defenses. Students found the program beneficial, providing hands-on experience in developing patentable products and aligning with their passion for scientific innovation. For instance, Alumna B-1 developed a complicated product from simple to advanced steps, and she enjoyed this process of creation. Alumni D-1 and E-1 perceived the patent program as a novel project that they never experienced. Moreover, Faculty members considered the patent program encouraged a shift toward applied research and an entrepreneurial mindset. Importantly, Faculty members observed that students began connecting their research to real-world applications, enhancing creativity and research focus. Faculty D, with extensive patent experience, strongly supported the program for fostering innovation.

> Faculty D stated: "Traditional Ph.D. is joining a lab, publishing a paper. You work through the program, you may not have entrepreneurship, or you know, commercial applications in ever. What I think is new is the possibility of a five-year track for a student to get their PhD and, at the same time, maybe have two or three provisional patents and a full patent by the time they graduate. I think that's a doable model. I could imagine folks in engineering, I can imagine folks in biology or physics, seeing the value of this, at any institution and see that model.

Yet, some faculty members also expressed a desire for more effective programs to connect patent projects with career exploration. Faculty D suggested an internship model to bridge academia and industry, while Faculty A cited another university's industry model as an example of helping students understand job market demands.

1.2 The urge for a conventional mindset change

Four out of five faculty members clearly expressed that students changed their mindset after joining the pilot program. For instance, Faculty C explained that the pilot program provided a practical opportunity enabling them to work hands-on to design the patentable product, including the consideration of material, cost, market, and so on. This realistic practice and learning challenges help students adopt a growth mindset. Faculty C also highlighted the abundance of patentable opportunities due to technological demands and viewed the patent pathway as a natural trend in his lab.

On the other hand, Faculty D acknowledged concerns about the patent program's workload, fearing it might extend beyond the five-year graduation timeline and hinder an entrepreneurial mindset. He urged both faculty and students to remain open-minded. Faculty B emphasized the importance of entrepreneurial awareness. Overall, faculty members suggested it was time for people to change their mindset in the background of applied science.

> Faculty C stated, “My student C-1 starts to think about what the cost is. How to evaluate the research from a different perspective. He is thinking, you know, in the future, how to integrate his research into the real world. We wouldn't expect a spiral pattern to create a business like Amazon or Facebook, or whatever. It's not realistic. But the realistic thing is that the mindsets changed for the students. I think that's a really big step. We shouldn't measure the success of seeing the business. We should measure success from this perspective. That's my opinion. Because it's really difficult to change people's mindsets, right?”

1.3 Student’s patent defense trial for doctoral degrees

In the current stage, the patent program was in the pilot stage, and it was neither a real model nor a patent defense. Frankly, six out of nine participants disclosed that the pilot program was no different than traditional paper defense. Three alumni claimed they went through the paper defenses. Alumni D-1 said he did present the patent in front of the university patent committee, but he used the three-papers defense to obtain his Ph.D degree eventually. Faculty A admitted that the pilot program was not a formalized model yet. Instead, they were exploring the possibility of program development and would share their experiences with other higher education institutions.

> Alumnus D-1 stated: “We filed a bunch of patents, but I still went on to do the traditional route of, you know, published papers and give the final dissertation defense with the, you know, 100 plus page dissertation all that kind of stuff, so I still did the traditional everything else.

Still, Faculty E criticized that the full patent was written by the lawyer but not the student. Although students and their advisors would work out a patentable product, that should be a provisional patent. However, it was not possible to make a full patent without a legal procedure. That was to say, the patent was a legal language. He thought the patent pathway program was over-promising in this regard.

2. Entrepreneurial course and training: Fundamental knowledge for developing an entrepreneurial mindset

All participants extended the significant value of entrepreneurial courses or training. The program cooperated with the university’s business school, and a course named “Entrepreneurial Decision” was open to the students in the pilot program. Moreover, there were some other entrepreneurial courses offered to students. For example, according to Faculty D, his student D-1 attended a lot of the venture prize training and completed a lot of presentations apart from the entrepreneurial course. Insightfully, the entrepreneurial program would invite various entrepreneurs to share their startup experiences. As a part of the course, Student A-1 was asked to interview the practitioners regarding their perspectives on product commercialization. Therefore, students transformed their mindset from basic science to applied science, the science could solve real-world problems.

> Student A-1 stated: “One thing that I can think of that helped me last summer, I enrolled in an entrepreneurial summer program. That helped me understand the focus of the patent part. But the program was completely different than what I thought; we had to interview

> people, like 15 people a week, random people from Food Lion or wherever, asking about our product, asking about what they would like, and a product things like that."

3. Transdisciplinary knowledge: Learning patent-related knowledge and skills.
Developing a patent requires massive knowledge and skills, which might not all be covered by the coursework. In terms of the complications of the patent application, students usually learn the scope of necessary knowledge about product development. Alumna B-1 made an effort to figure out the difficulty of electrical circuits. For instance, she had to learn new programming and optical design. Faculty B agreed with the importance of transdisciplinary knowledge, which the student should embrace and apply the different skills to solve authentic problems.

> Alumna B-1 stated: "I needed to learn everything from scratch. Because of the other parts that are very complicated, I knew that you'd learn everything from zero form and understand everything very well, and be able to make the device work, make it work."

4. Financial support: Funding for conference, equipment, and a startup business
Financial support from the patent program was crucial, enabling students to attend professional conferences, purchase equipment, and conduct internships in the industry. This funding facilitated travel to prestigious conferences, such as an international conference in Washington, DC, where student A-1 networked with industry professionals. Alumna E-1 traveled to Japan to present her patent progress, an opportunity made possible by the program's funding. The faculty observed that managing these funds provided students with invaluable experiences. Faculty E highlighted the importance of funding for international conferences despite the high costs.

> Alumna E-1 stated: "Providing some funding to support the student to go out there and communicate their ideas with other people in that industry is very important. And that's what the patent program did for me. It allowed me to go to these conferences and talk to people who were trying to sell this kind of similar technology."

Furthermore, Faculty B, with startup experience, suggested students seek small business funds for long-term entrepreneurship post-graduation. Although this funding was outside the patent pathway's scope, it was essential for supporting students pursuing startups. Faculty A considered industry cooperation but was concerned about patent ownership complexities.

5. Role of advisor: Academic support and patent experience
None of the students opposed the academic supervision and support from their advisors. All students were introduced to the patent pilot program by their advisors. For instance, Alumni D-1 and E-1 cooperated with their advisors to work out all the paperwork for the patent report, and they are co-inventor relationship. Alumna E-1 emphasized the predominant factor in which students shared the same research interest with the advisor due to the challenge of patent development.

Additionally, advisors' full patent experience boosted students' confidence to initiate a patent program. Faculty with more patent licenses or who even own a startup company would set a role model for students. Students were able to foresee the tangible future from their experiences.

Most importantly, students realized that basic science could turn into manufacturing and accomplish product commercialization.

> Alumnus D-1 stated: “I think the biggest thing is having an advisor or other professors who have done this before, have published patents before.”

> Faculty B stated: “All of my patents were either with students or with professional colleagues. I have set up the company, and it was with my PhD students.”

6. Role of university: Faculty, department, and research division support
The principal investigators played a crucial role in promoting the patent pilot program across STEM departments. Faculty A noted recruitment challenges during the pandemic, but acceptance has grown since 2020. The team held workshops, approached potential participants individually, and collaborated with the business school for entrepreneurial courses. When patents were ready for licensing, the university's research division provided professional advice on intellectual property protection. Alumni D1 found this legal guidance invaluable. Faculty A emphasized the need for more manpower to advance the program at both the departmental and university levels.

> Alumnus D1 stated: “I think the division of research is super helpful with all of the patent stuff. Because we emailed them many all time, trying to figure out, you know, what we need to file, what do we think can be covered in a patent, all that kind of stuff. And then they often have us talk with the attorneys directly as well, you know, how do we get things filed, what can we cover, what can we claim, what can we not claim, all those kinds of things.”

7. Patentable entrepreneurship: Not for any graduate student
The patent pilot program provided students a practical opportunity to conduct a provisional patent, but multiple factors influenced the filing of a patent. For instance, Faculty D illustrated that a successful patent depended on the need of the product and market, the cost of the material and manufacture, and technology support. What’s more, Faculty B seriously pointed out the hardship of the startup for graduate students. Upon being an entrepreneur, people might live on very low pay or even no pay, work for long hours, and diversify different skills. People survive before the product can be sold to the buyer, but it is not a guarantee that the product will be commercialized. Due to the fact that small startup business was not for every graduate student, as it was a high-risk decision. Still, Faculty B told the truth that STEM graduate students were good enough to find a decent job that could afford a house and a car.

> Faculty B stated: “Because a lot of students I've met up they are not, I mean, not many people when they graduate from a university think of making a business on their life insurance for patent development. Most of the students who graduate can get a job and earn lots of money straight away, and houses and cars, and things like that. I would think it wouldn't be for anyone who wanted to put a company together with the patent program. It is not necessary.”

In addition, international students' attitudes towards the program were notable. Alumni B-1 and Faculty A mentioned concerns about paper publication numbers, which are crucial for those planning to apply for U.S. green cards. International students often prefer organizations that sponsor their green cards over entrepreneurship, which carries significant risks. Only one-fourth of the program's participants were non-domestic students.

Table 3
Descriptive analysis of thematic coding of the patent pathway pilot program

Coding Theme	Coding Number of Participant	Coding Number of Reference	Coding Number of Reference (%)
Patent Pathway Pilot Program			
Patent pathway for Ph.D. degree	7	64	35.36%
Recruitment difficulty at the beginning	1	29	16.02%
Need to change conventional mindset	5	26	14.36%
Patent defense no difference from paper defense or underway development	6	19	10.50%
Expect more effective patent model	3	14	7.73%
Not clear about the patent procedure	3	10	5.52%
Patent written by lawyer	2	8	4.42%
Technology environment opportunity	1	8	4.42%
Pandemic influence	1	3	1.66%
Total	-	181	100.00%
Entrepreneurial Course and Training			
Entrepreneurial course or training	9	41	83.67%
Entrepreneurial course selection difficulty	1	5	10.20%
Elective business or patent class option	1	3	6.12%
Total	-	49	100.00%
Financial Support			
Financial support for conference travel	6	21	22.11%
Talk to people to understand the need of research	6	17	17.89%
Fund supporting from patent program	4	15	15.79%
Fund from other grant to startup company	4	12	12.63%
Financial support for equipment purchasing	6	10	10.53%
Financial support for Internship in industry	1	7	7.37%
Fund concern for patent ownership	1	5	5.26%
Fund concern to startup in the blank period before receive funding	1	5	5.26%
Talk to entrepreneurial community for free startup advice	1	3	3.16%
Total	-	95	100.00%

Role of Advisor			
Receive support from advisor and share same research interest	4	19	57.58%
Professor has patent filing experience	5	12	36.36%
Professor startups company with student	1	2	6.06%
Total	-	33	100.00%
Role of University			
Department faculty and chair support	7	23	60.53%
University Effort	2	9	23.68%
University research division supports intellectual property protection	1	6	15.79%
Total	-	38	100.00%
Patentable Entrepreneurship			
Risk to startup small business	3	21	39.62%
International student dilemma	3	11	20.75%
Risk to patent a product	4	10	18.87%
Patent not for any graduate student	3	9	16.98%
Know financial support source from university	1	2	3.77%
Total	-	53	100.00%

Research question 2: What influential education outcomes do students achieve in the patent entrepreneurial pathway program?

1. Academy outcome: Patent defense trial, provisional patent, and paper publication
All four student participants experienced the preparation of provisional patents. For all that, only Alumnus D-1 had full patent experience and communicated with the university's patent committee. He completed two full patents during his Ph.D. study and one during his post-doc period. Despite trying the patent defense in the pathway program, he ended up with the traditional paper defense, ultimately, which was attributed to the underdeveloped pilot. Meanwhile, alumni B-1 and E-1 worked with their advisors on the manuscripts about the provisional patents, but the protocol failed to move forward because of technological reasons. Student A-1 is collecting the data for the first manuscript regarding the provisional patent. Faculty D and Faculty E believed that manuscript or paper publication was an unavoidable procedure to apply for the provisional patent because the publication or proposal provided the attorney with the background for patent protection. Moreover, the importance of the publication was rooted in all participants' minds, especially students. According to participants' lived experience, patent development would be beneficial to the paper publication.

> Alumni D-1 stated: "Two of them were sent to the US Patent Office during my PhD. On the very first one, we add the, what would you call it, like a patent defense in front of the UNC Charlotte patent faculty group. And then they recommended it to be a Patent Cooperation Treaty (PCT) international patent. So, that was it was really good. It was

good to get feedback, where it can be improved, what we're kind of missing, that kind of thing."

2. Career outcome: Industry, government, and small business startup

Student participants were satisfied with the applied research focus of the patent pathway program, expressing strong interest in solving real-world problems and product commercialization. Alumna B-1, now an optical scientist in the industry, appreciated the program despite not continuing to publish papers. Alumna E-1, a physical and optical scientist in the government, became a principal investigator and plans to apply for internal grants. Alumni D-1, pursuing a post-doc, is preparing to start a small business with his advisor. Faculty B noted that STEM international students often find employment and U.S. green card sponsorship through the industry. The program helped students recognize their career paths, with employers of Alumni B-1 and E-1 identified through the program. Faculty A highlighted that the hands-on, product-oriented research cultivated problem-solving skills and entrepreneurial mindsets. However, some students remained uncertain about choosing academia or industry in the future, reflecting the program's role in fostering decision-making under uncertainty.

> Alumna B-1 stated: "Although I like doing research kind of work but, um, I know my personality. So, I think my personality is closer to the industry than being a faculty member. The reason is not because being a faculty very competitive and hard to get a position sure. Yes, it's mostly on my character base. That's the reason. For a green card, fortunately, um, there is a way to, like, I applied through a National Interest Waiver (NIW) based on my research work and preliminary publications. And I am on the path, like, I have already applied, and everything is going well, and I will have it in a new future hopefully. And that's enough to have a green card. And you don't need to be faculty to be able to apply, um, with your publication, and stuff. I could see their (senior graduated students) success and wanted to go on similar path."
>
> Faculty B stated: "So they don't have as much of a problem getting visas cuz they can often find employers for support that an application."

Table 4

Descriptive analysis of thematic coding of the student learning outcomes

Coding Theme	Coding Number of Participant	Coding Number of Reference	Coding Number of Reference (%)
Academic Outcome			
Provisional patent submission successfully	5	27	32.14%
Provisional patent submission unsuccessfully	5	23	27.38%
Paper publication	5	19	22.62%
Seek new grant opportunity with more data evidence	1	10	11.90%
Experience patent defense	1	3	3.57%
Patent experience helps grant writing	1	2	2.38%

Total	-	84	100.00%
Career Outcome			
Satisfaction working in industry	3	15	36.59%
Wonder the career in industry or academia	3	7	17.07%
Startup a company	1	7	17.07%
Help student find job and think of career trajectory	2	6	14.63%
Work in government being a PI	2	4	9.76%
Work in Industry but not publishing paper in the future	1	2	4.88%
Total	-	41	100.00%

Research question 3: What aspects of the entrepreneurial mindset do students and faculty perceive in the patent pathway program?

1. General entrepreneurial mindset

1.1 Cooperation

Three students talked about how essential cooperation and teamwork were. Student A-1 and Alumna E-1 revealed that their works were cross-disciplinary projects, so they collaborated with different people often. Alumna E-1 deemed that each teammate had a unique role and contributed their expertise, which could represent this value from the publication. As a graduate student, Student A-1 received a lot of help in conducting the research from the team, which were from the university and the company. They emphasized that cooperation would facilitate their success.

> Student A-1 stated: "Ove,rall some of the people that work with the company, they're still here at school working, but they're not students, so they have different mindsets and different pieces of advice. Because the people I'm working with because it's very interdisciplinary, some people have stronger backgrounds in chemistry. So, I'm struggling with that, just go talk to them. It's not like there's pressure on you, I have to figure this out by myself. So, we all kind of fill in the gaps for each other. So, it is good."

1.2 Creativity and Innovation

Three alumni stood out for their characteristics of creativity and innovation. They showed a strong interest in creating and developing new technology from a young age. Alumna B-1 said she liked the imaginary ideal and made it come true in the practical world, and that was her motivation. Alumnus D-1 enjoyed the discovery of new things, just like creating patents. He started up a company, but he said he did not expect many fantastic things in the early stages. Instead, he was motivated to go on an innovative adventure. Alumna E-1 had an intrinsic interest in developing new cutting-edge technology, and she heightened the novel idea from her patent experiences.

> Alumna E-1 stated: "I wanted a 3D print this kind of device, which no one had tried to do before. And there was just, there was an empty row on this table. I mean, you kind of have to think outside the box. So, being successful in coming up with an idea, that's cool.

> So, that's important. I would say, for students to understand, is, you know, come up with your idea, it is novel, yes, it's novel."

1.3 Lifelong learning, leadership, and professionalism

Alumna B-1 and Student A-1 found learning exciting and saw it as an incredible journey. Despite technical difficulties, students pursued perfectionism in their work. Alumna B-1 persisted through challenges, witnessing project progress and refusing to give up. Leadership was another key trait among students in the patent program. They identified research gaps, initiated information searches, and led product development like entrepreneurs. Alumna E-1 demonstrated leadership by recognizing a 3D printing research gap, working on it until provisional patent preparation, and using her experience to apply for grant funding and lead projects in her job.

> Alumna B-1 stated: "We want to do a good job. The purpose was not to make it easier. The good thing is we had good progress every time, so we did not feel that we needed to make it easier because we had good progress. I see capability was there, so why not use it as much as possible?"

2. Specific entrepreneurial mindset

2.1 Applied research

The faculty stood up for the patent pathway program. For example, Faculty C observed that his student developed a fundamentally different mindset, which was from small-scale to micro-scale, considering the cost, market, customer, and consumer. The changing mindset enabled the student to reshape the meaning and need of their research. Faculty D hoped his students would be involved in the patent pathway because he deemed the project connected to the real world and how basic science was anchored to problem-solving. He encouraged students not to isolate the basic science and applied science, which used technology in the real world, but not just for experiments in the lab. Besides, Faculty E disagreed with the student's focus on the result and thesis because they were far away from the realm of application. Overall, faculty members appreciated the patent program exposing students to solving real pain-point problems in human life. Students nurtured the applied awareness when conducting the patent program.

> Faculty C stated: "Previously, without this program, they would consider doing some fundamental research, figuring out what is going on at the very small scale, like the micrometer or nanometer level, right? And then they don't care about how well this is practical in the real world, right? After this program, although they probably will still deliver some papers and conferences, use the money for travel, instead of filing a patent. But I want to tell you that the difference is very obvious. Students start to think about the research from another perspective. For example, they will consider if we use this material, what the cost is going to be if we launch this discovery to the market, right? And then they will consider whether they will be environmentally friendly or not, right? So, if they don't join this pattern program, they will not think this way, right? They will only think about how to address this fundamental issue, right?"

2.2 Product commercialization and small business startup

Product commercialization was not only evidence of how the research outcome served human beings, but it also brought economic profit to researchers. The significance of patent commercialization was not only academic success, but it was the knowledge-transfer transformation to the scholars. Students understood that the industry or company would help their patent protocol turn into a real product to sell on the market. Furthermore, especially experienced faculties, they would identify the commercial opportunity and supervise their students to license a patent that can further develop a startup. That was how the entrepreneurship mindset was nurtured. Mindset changing requires an innovative and incentive educational program.

Yet, Alumni E-1 explained it was difficult to come up with a successful technology patent because of various commercial needs in the business environment. Still, Faculty E advocated trying the patent program to build a professional network in the entrepreneurial community for a future career trajectory. As discussed, the startup was not for any graduate student. The startup required a lot of professional support and depended on personal character. For instance, Alumnus D-1 emphasized the entrepreneurial mindset from the science significance perspective instead of the startup business.

> Alumnus D-1 stated: "This is the biggest challenge, probably the biggest challenge would be, you know, whenever, actually, I'm gonna change that. The biggest problem is it's a completely different way of thinking. So, in chemistry or nanoscale science, we're constantly thinking of, you know, what the science says, and where can we go with it scientifically, and how can we do this in the lab, versus doing the entrepreneurial side of it and kind of patenting side of it. It is more of how this is usable in the real world, as they are very different from how we can do this in the lab. So, it's that's the big transition, you know, going from really small to just huge, of like how do you translate research into a patent or research into commercialization."

2.3 Intellectual property protection

Faculty who had startup experience and students who shouldered the leading role in the project presented a strong sense of patent property protection. For instance, Alumna E-1 learned a disappointing lesson from the patent project. She had an idea for 3D printing that was co-invented with her advisor, but she found this protocol had been published by another team when she presented her findings at the conference. Though that team conducted more advanced technology for the product, she realized how important it is to protect the patentable idea and applied for the provisional patent as a scientist. Besides, she highlighted that before selling the product prototype to the company, a researcher should apply for a provisional patent to protect intellectual property because the technology would be exposed to the producer or manufacturer.

Two entrepreneurs, Faculty B and Alumnus D-1, declared that a patent was a way to prevent their technology idea from being stolen by other people. Alumna E-1 implied that new technology might not apply value to the public immediately since it was a cutting-edge technology. Still, it might be in demand in years. Critically, filing a patent could protect your discovery whenever the technology is well-known or utilized. In a word, the product development would initiate scientists' sense of patent filing to protect their idea. From the participants' experiences of the patent pathway program, intellectual property protection was one of the most important elements regarding the entrepreneurial mindset.

> Alumna E-1 stated: "You want to continue developing your product and make it more valuable before you go out there, and want to sell 5-10% of your business to get it going. So, protecting your ideas is something really important. That's my main motivation outside of the money. I mean, money's great. But at the end of the day, if you don't fight for your product to get big and to make a lot of money, it won't. Protecting your product is important, protecting your ideas whether it's needed now in the next 5 years because it's a cutting-edge technology, or whether it's something that people haven't even. That's not even on people's radar yet, but that will be very important in 10 years; you just want. I want to know how to protect my intellectual property. That's not something that you get along the normal path of getting your PhD, but it's important as you're going out into the world and wanting to be a PI. So, I'm grateful for that because I feel like I have a better understanding to say."

Table 5
Descriptive analysis of thematic coding of the entrepreneurial mindset

Coding Theme	Coding Number of Participant	Coding Number of Reference	Coding Number of Reference (%)
General Entrepreneurial Mindset Outcome			
Cooperation	3	19	35.19%
Creativity and innovation	3	15	27.78%
Desire to learn and grow	2	4	7.41%
Leadership in research	1	4	7.41%
Pursue profession	1	4	7.41%
Respect and understand people's choice or situation	1	4	7.41%
Time commitment	3	4	7.41%
Total	-	54	100.00%
Specific Entrepreneurial Mindset Outcome			
Applied research and problem-solving	7	38	26.03%
Patent a product	7	27	18.49%
Product commercialization and market consideration	8	24	16.44%
Patent property protection	3	24	16.44%
Small business startup or entrepreneurship	7	21	14.38%
Interest of patent pathway program	5	12	8.22%
Total	-	146	100.00%

Discussion

The patent pathway program provided STEM doctoral students an alternative route to earning their doctoral degree. The patent defense is a transformative pilot program in higher education [1]. A key advantage is its alignment with applied research, encouraging students to develop cross-disciplinary knowledge and real-world problem-solving skills. Participants, both faculty and students, emphasized the provisional patent applications and potential full patent filings. Additionally, the program also fosters students' entrepreneurial mindset, with some students leveraging their patents to launch startups. It is suggested that universities can provide more research opportunities for students to engage the patentable projects and shape entrepreneurial awareness. For instance, Students expressed interest in participating in federal-funded innovation programs such as the National Science Foundation's Innovation Corps (I-Corps™), National Institutes of Health (NIH), Small Business Innovation Research (SBIR), and Small Business Technology Transfer (STTR) programs. Furthermore, for students who already possess the provisional patent, they anticipate professional advice for intellectual property policy and regulation. To illustrate, participants expect the university can integrate intellectual property courses, i.e., Patent Cooperation Treaty (PCT) and non-disclosure agreement (NDA), into their course syllabus to enhance their property knowledge and awareness. Besides, to connect rigorous research and practical industry, the university can consider career training for students to equip them with qualified skills and develop career trajectories, e.g., the Accelerate to Industry (A2i)™ program. In a word, higher educational institutions and policymakers should integrate engineering entrepreneurship elements into the curriculum design and related support programs to create a sustainable, patent-concentrated graduate program. This approach aims to enhance students' applied science experience and better prepare them for a professional career [3].

However, it is still in the protocol development stage, and there is no uniform model for patent-based doctoral defenses. There are some drawbacks and challenges in this innovative patent alternative program. First of all, students reported that they learned entrepreneurial knowledge from the business school, which did not mainly focus on engineering. Indeed, students were eager to explore how to apply for and participate in innovative entrepreneurship programs. Secondly, the importance of paper publication was emphasized by participants, either faculty or students. According to faculty's supervision experiences, the three-paper defense was the conventional defense evidence in doctoral education. The patent pathway program still publishes the papers because the manuscript is also one of the essential documents to apply for the provisional patent and the full legal patent. To further develop the program, the researcher should justify the difference between patent defense and paper defense. Besides, patents are primarily legal documents drafted by lawyers, which may not fully align with academic research standards. Moreover, international students might prioritize employers who sponsor U.S. work visas over entrepreneurial ventures. In terms of the role of an entrepreneur, an international student might face visa challenges, although a full patent product can incubate a small business. For example, international students will be concerned if the start-up company provides them with a valid working visa. On the other hand, domestic students may hesitate to be entrepreneurs due to unforeseen funding challenges. Overall, these barriers highlight the need for institutional support, such as mentorship and early-stage funding, to help students transition from patent holders to entrepreneurs. Fundamentally, STEM education is a combination of basic science and applied research. Referring to the federal document of STEM education issued in 2024, one of the objectives is to increase universities' evidence-based STEM instructional materials, transdisciplinary learning, technology facilities, and knowledge that can transform into product creation [23]. Crucially, entrepreneurship is one of the approaches to achieve those aims [23]. It is believed that the patent pathway program is an evidence-based program that can sustainably develop in the long term, but an ecological system should be built up to accomplish its educational outcomes.

Limitations and Future Study

First and foremost, there are nine participants in this study, so the smaller participant pool cannot represent all STEM students. The students and faculty members in the patent pilot program are mainly from mechanical engineering and chemistry. In the future, broader STEM disciplines (i.e., biology and electrical engineering) can be invited to the study. Secondly, the patent program recruitment was difficult to implement. Undeniably, only a few doctoral students were willing to participate in the patent program, concerned about the workload, time commitment, and graduation timeline. Moreover, this study did not take the stakeholders into account, like entrepreneurial course instructors and patent protection office officers. Meanwhile, the data was collected from a single urban university, so a future study can expand to more higher education institutions to yield more comprehensive insights. Methodologically, this study only captured end-of-program perspectives, even though the pilot study lasted for about three years. The additional longitudinal design, tracking participants from program inception through career transitions, would better assess students' long-term outcomes influenced by the patent pathway program, such as startup success or industry impact.

Conclusion

The Patent Entrepreneur Pathway Program represents an innovative approach to STEM doctoral education, combining academic rigor with real-world applicability. Although still in its developmental stage, the program faces challenges such as the lack of a standardized model and the legal complexities associated with patenting. Further empirical evidence, particularly from longitudinal studies, is necessary to assess its long-term impact on graduates' careers and the broader STEM ecosystem. The success of the program depends on collaboration among universities, policymakers, and federal agencies. Sustained support from both higher education institutions and government bodies is critical for evolving the initiative into a scalable model that addresses the demands of modern STEM education and innovation-driven economies. By fostering an enabling environment and addressing existing challenges, the patent entrepreneur pathway can play a significant role in advancing STEM fields.

This study explores doctoral students' and their academic advisors' experiences and perceptions regarding the patent defense achievement. Faculty members share valuable reflections, noting observable changes in students' behaviors and mindsets throughout the pilot program. They appreciate the program's impact and advocate for its expansion to a wider student audience. Most importantly, faculty observe that students develop entrepreneurial mindsets and discover passionate career paths as a result of participating in the program. From the students' perspective, both on-campus graduate students and alumni report strong intrinsic appreciation for the patent program. Their lived experiences highlight how participation fosters alignment between their academic training and career aspirations, ultimately leading to significant academic and professional fulfillment. To conclude, the findings demonstrated that students successfully cultivated an entrepreneurial mindset from the time they joined the pilot program. It lays the foundation for graduate students' entrepreneurial awareness and applied science skills that can be further developed within their careers.

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