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Faculty Perspectives on Their Role in the Training of STEM Doctoral Students

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Abstract

Traditional PhD training in STEM fields places a strong emphasis on developing doctoral students' academic skills, encompassing research, academic writing, sharing of knowledge through publications and conference presentations, etc. However, with the ever-evolving expectations of graduate training, particularly in applied fields, the demand for PhD has transcended the confines of academia. For instance, nearly 90% of engineering PhDs will not enter academia upon graduation, which underscores the discrepancy between the current PhD training programs and the preparation of students for future careers. To better support doctoral students especially for those who intend to pursue positions in industry including corporate R&D labs, national labs, defense organizations, healthcare institutes, etc. an innovative program called Pasteur Partners PhD (P3) was launched specifically for the training of such doctoral students. It is a student-centered doctoral training program based on use-inspired research in partnership with industry.

A preliminary evaluation of the P3 program revealed that students benefited significantly from gaining practical skills through industry involvement such as co-advising, resulting in a clearer understanding of how the industry operates, which, in turn, enhanced their employability in the industry. The University administration also provided significant support for the program. However, a broader implementation of P3 encountered hesitancy from faculty members. Many were against or unsure about the need to amend the structure of STEM doctoral training. To examine the challenges and obstacles that the faculty members felt towards making substantial changes across the board, we conducted a survey to assess their perspectives on three specific aspects: (i) faculty members' roles and responsibilities, (ii) perceived challenges and resources needed to satisfy (i), and (iii) the skills and training needed for student centered doctoral training. Altogether 125 of faculty members responded to the survey. The key outcomes of their responses are as follows:

The faculty valued preparing PhD students as (i) researchers with expertise in the field, (ii) becoming successful as a faculty member in academia, and (iii) fostering skills valued by the industry about equally important, but much less to become an entrepreneur. The PhD supervisors were considered to be the main stakeholder for building academic ($n = 108$) and non-academic capacities ($n = 69$), whereas entrepreneurial capacity building was considered a responsibility of external professionals ($n = 49$). Whereas the majority of faculty highly valued preparing the students for careers in industry, the limited access to industry-specific knowledge appeared as the main impediment to achieving this goal. There was a general consensus for providing certain non-technical skills and encouraging students to collaborate with non-academic partners. However, there was also some concern about funding, potential disruptions, and the need for institutional support for establishing collaborative efforts, underscores the necessity for a multi-faceted doctoral training approach to support doctoral students more effectively.

We believe that the insights reported here will help in designing support systems that will empower faculty to contribute to the training of doctoral workforce for the benefit of society at large. It will also inform curriculum development and help prepare students better for a wider range of career paths.

1. Introduction

PhD training holds a crucial role in higher education within STEM disciplines, traditionally focusing on enhancing doctoral students' academic skills, including in-depth research on a scientific question or engineering problem, communication of newly generated knowledge to peers through conference presentation and publication. However, the evolving landscape, particularly in technology-related fields like engineering and applied sciences, has expanded the demand for PhD degree holders beyond academia. Industries across various sectors actively seek PhDs to advance technology through research and development in mission-driven settings. Here we define ‘industry’ broadly to include private corporations, national labs, defense research organizations, health institutes, etc.

This shift in demand has led an increasing number of STEM PhD students to pursue or consider careers in industrial contexts, revealing a misalignment between current PhD training programs and preparation for future employment [1,2]. Most PhD programs tend to be academically oriented, lacking alignment with the industry's demands. In response, a few higher education institutions have introduced programs allowing or encouraging doctoral students to engage with the industry during their academic training [3-5].

Evaluation of these initiatives has shown that students benefit significantly from practical industry involvement, gaining skills through internships that enhance their understanding of industry operations and, consequently, improve their employability. Our study showed overwhelming interest from graduate applicants for pursuing the Pasteur Partners PhD (P3) model, which explicitly requires the student to be trained comprehensively in partnership with industry [6]. In this model, a student designs and executes his/her PhD with a co-adviser from industry besides the academic adviser, completes a one to two semester long Residency at the industry partners’ location, and takes 3 to 5 essential skills one-credit courses. Despite the positive outcomes, the implementation of the P3 program has faced challenges and resistance from faculty members [7]. Only a limited number of faculty, primarily at the junior level, have expressed interest in participating in this mode of training, underscoring the prevailing emphasis of the doctoral education system on research output (publications) rather than the practical relevance of student training practices.

To understand the source of lack of faculty enthusiasm for changing the training of PhD students to prepare them better for successful careers in a non-academic environment, we undertook the present study and sought the feedback of the faculty of 13 STEM departments at our university. We sought to gain an insight of their perspective, especially about their expectation of a PhD degree, perceived challenges, and actual obstacles from an institutional and systemic perspective. With this knowledge we hope to address the present challenge of doctoral training of the students who aspire to enter the industry upon graduation.

2. Design of the survey

Our goal was to survey the perspectives of all the faculty members who contributed to the training of PhD students in any way, such as academic adviser, dissertation adviser whether or not providing research assistantship, course instructor, dissertation committee member, qualifying exam organizer, etc. The survey was collaboratively developed by the authors who themselves were faculty members in the College of Education, the College of Engineering and Applied Science, and the College of Arts and Science since the goal was to survey the perspectives from all the STEM fields. It aimed to comprehensively understand the primary objectives of doctoral training within different STEM fields, exploring variations across disciplines and identifying faculty members' perceptions of the most significant goals in their areas of expertise. The survey consisted of three main components: (i) Roles and Responsibilities, (ii) Perceived Challenges and Resources Needed, and (iii) Skills and Trainings. The actual survey document is provided in the Appendix for readers interested in detail.

The design of the first component, *Roles and Responsibilities*, was informed by Ford et al. [8], which suggested that faculty members' self-perceptions of their roles and responsibilities in training PhD students play a crucial role in shaping the doctoral experience and future career development. For instance, a faculty member who identifies more as an academic advisor is likely to focus on cultivating students' academic skills. On the other hand, faculty members who see themselves as mentors may prioritize the development of a broader set of skills for their students. Thus, understanding faculty members’ perceptions regarding their roles and responsibilities in providing doctoral training could shed light on their rationale for offering support and guidance to their students. This component consisted of four questions focusing on the roles and objectives that the individuals identify as crucial. The questions also prompted participants to rate the importance of these aspects and specify the stakeholder they believe should be responsible for providing the specified training.

In the second component, *Challenges and Resources*, the survey focused on the impediments or challenges that the faculty members felt in striving to fulfill the four doctoral training objectives mentioned in the aforementioned component. Additionally, it asked to identify the corresponding resources that could be helpful in managing these challenges. Each question was followed by an open-ended section, allowing participants to provide additional information not included in the predefined list. This component was essential as it could reveal insights into potential obstacles that hinder faculty members from fulfilling their expected roles and responsibilities when training PhD students. Moreover, their perceptions about the required resources to overcome these challenges could offer practical recommendations for institutions to optimize resources at the program or college level, aiming to improve the system and better cater to faculty members’ needs.

The third component, *Skills and Trainings*, was informed by a scale developed by Crisp and Cruz [9]. This component emphasized faculty members’ perceptions regarding the importance of multifaceted qualities and skills beyond subject matter expertise, such as communication or problem-solving. The outcomes enabled us to understand how faculty members would balance different skills or prioritize certain abilities while training their PhD students. It consisted of five items where participants were required to rate a series of abilities, beyond subject matter expertise, that a successful PhD student should possess — such as effective communication or project management — ranging from very important to not important. An open-ended question was provided for additional thoughts. Participants were also asked to express their views on the extent to which they believe a faculty should foster both academic and industrial experience development in PhD students, using a Likert scale from "Not at all" to "To a great extent." A follow-up open-ended question allowed the participants to provide their rationale. Additionally, participants were questioned about their willingness to encourage collaborative research between their PhD students and non-academic (i.e. industrial) partners.

3. Survey process and analysis

Convenience sampling was utilized in survey dissemination. Every faculty member in the 13 STEM departments was sent the link to the survey via email. A reminder email was issued a week later to increase the survey response rate. In total, 125 faculty members completed the survey, yielding a response rate of 47%. To ensure the anonymity of the survey, the raw data was processed and analyzed by an evaluator from the College of Education, who is the lead author of this article.

Descriptive analysis was conducted on quantitative data obtained from the survey, along with visualizations, such as bar or pie charts, to reveal insights into faculty members' perceptions about doctoral student training. As to qualitative data from the survey, an inductive coding process was performed [10]. We extracted the main themes after reviewing all the data under each open-ended question, then an axial coding method was applied to examine if there were connections between each theme. The coding process was carried out iteratively using constant comparative methods [11]. Throughout the coding and recording process, the themes were verified, organized, and refined.

4. Survey outcomes

4.1. Demographic information about the participants

The 125 survey participants represent various programs and departments across academic structures, showcasing a diverse range of disciplines. They include Astrophysics, Bioengineering, Biological Sciences, Chemical and Biomolecular Engineering, Chemistry, Community Health, Computer Science and Engineering, Electrical and Computer Engineering, Industrial and Systems Engineering, Materials Science and Engineering, Mathematics, Mechanical Engineering & Mechanics, and Physics. Among these units, Mechanical Engineering and Mechanics hold the highest proportion (20%), followed by Biological Sciences (15%), Mathematics (15%), and Bioengineering (12%), the remaining programs contributed less than 10%. This distribution underscores the disciplinary breadth of STEM fields and the varied academic backgrounds contributing to the survey. While analyzing the results the participants were categorized into two groups based on the nature of their research discipline: curiosity-driven (CD) or use-inspired (UI). Faculty members in the CD category indicated that their research primarily focused on exploration, including the advancement of a field and theoretical development without any consideration of the technological or societal needs. Faculty members in the UI category indicated a research direction that was determined at the very outset by a clear, practical need which could be defined by a sponsor or identified by the investigators themselves. Overall, 37% of the participants belonged to the CD category, and 63% to the UI category.

Participants presented a range of experiences in training doctoral students (see Fig. 1), ranging from 2 years to over 40 years. A majority of them fell within the category of 10-20 years of mentoring experience (53%), followed by 35% with less than 10 years of experience. Additionally, 12% of participants possessed over 20 years of experience. This diverse distribution depicts a long-established doctoral training environment in the institution.

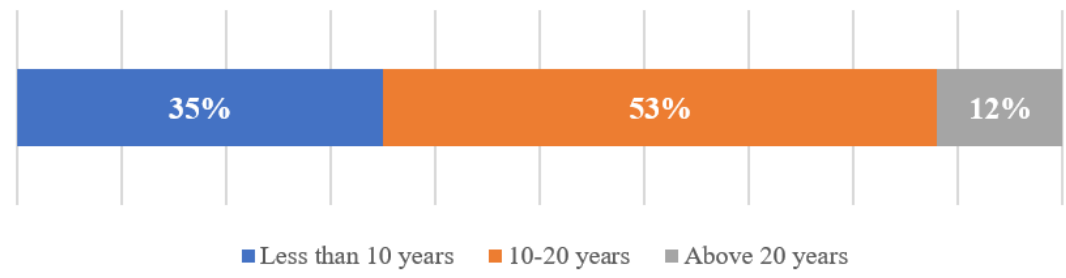

Fig. 1. Demographic information about the participants according to the number of years of their involvement in doctoral training.

4.2. Primary role(s) and responsibility of the faculty members

Participants were asked to identify their primary role(s) in the doctoral training of students. This question allowed them to select multiple roles. The results indicated a broad distribution among the respondents (see Fig. 2). The most frequently chosen role was that of a mentor, with 101 participants (22%) selecting this option. Following closely, 21% of the participants (n = 98) identified themselves as dissertation committee members. Moreover, 21% of the participants (n = 96) mentioned serving as research supervisors providing financial support. Academic advisor and instructor of graduate courses roles were identified by 19% (n = 86) and 17% (n = 81) respectively. These findings indicate that faculty members acknowledge the multitude of roles they must fulfill when training doctoral students. Notably, there is no predominant role that especially stands out. Nevertheless, one faculty pointed out that they should also provide doctoral students with emotional support and career guidance.

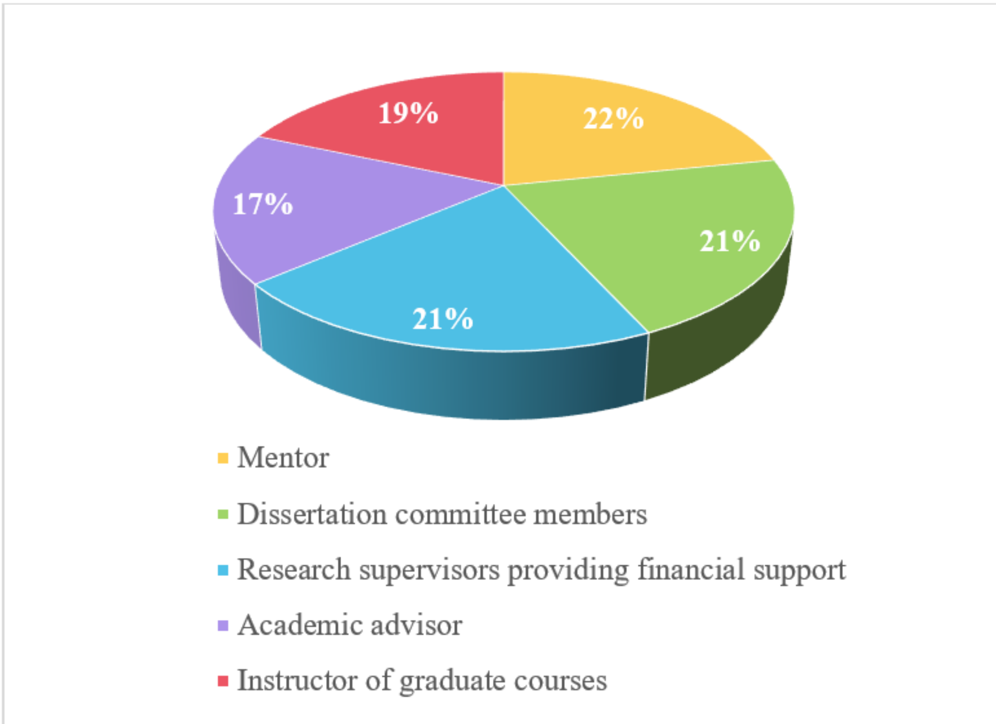

Fig. 2. Distribution of primary roles as identified by the faculty members for themselves.

When asked about the main objectives that the faculty members consider for training doctoral students, the largest number, 34% (n = 115), identified developing advanced research expertise in the discipline (see Fig. 3). Another comparable objective, highlighted by 30% (n = 100) of participants, was training PhD graduates to succeed in academia. Fostering skills valued by the industry was valued third (29%, n = 99) with a small fraction of respondents mentioning preparation to become an entrepreneur (7%, n = 25). In addition, beyond the choices listed, faculty members also mentioned that it was essential to nurture "imagination, curiosity, independence and critical thinking skills in students" as well as "professional skills, including communication, teaching, and problem solving." They indicated that as these intellectual skills were instilled, all listed objectives will be automatically achieved.

The questions about developing specific abilities in doctoral students attempted to differentiate the needs of careers in academia vs. non-academic organizations (such as private companies, national labs, defense organizations, healthcare, etc.) or entrepreneurship. The faculty considered the importance of the first two capacities about the same (see Fig. 4). The majority of the answers considered building capabilities for success in the first two types of careers extremely and very important. No one indicated that building these capabilities was not important. Interestingly, more faculty considered non-academic capacity building (n = 54) extremely important than academic capacity building (n = 48). In contrast, for entrepreneurial capacity building, the majority of the answers marked it as important (n = 40) or slightly important (n = 44), whereas 21 answers considered it not important. These outcomes indicate that faculty members place a similar emphasis on capacities for both academic and non-academic capacities, but notably less on entrepreneurship.

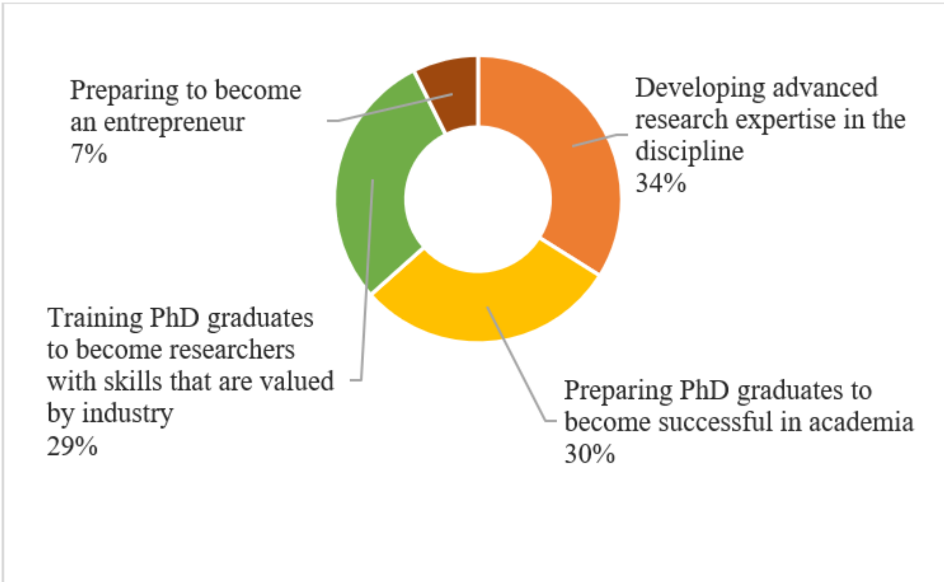

Fig. 3. Distribution of main objectives as identified by the faculty for their role in doctoral training.

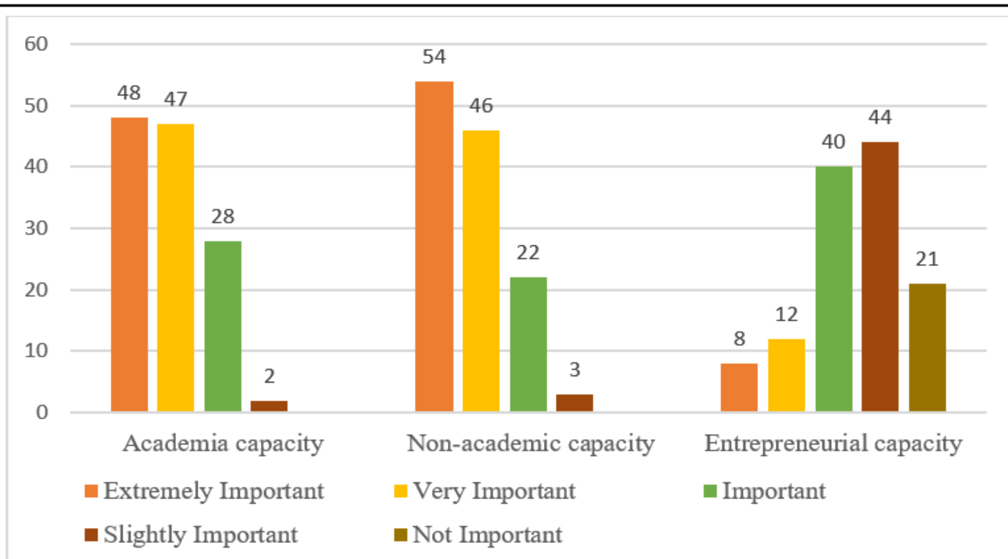

Fig. 4. Faculty's assessment of the relative importance of the three capabilities (for academic, non-academic and entrepreneurship careers) that should be developed in doctoral students.

The follow-up questions inquired about faculty members' recognition of the stakeholders who should be primarily responsible for each type of above-mentioned training (see Fig. 5). They considered that the PhD supervisor should be the main stakeholder for both academia (n = 108) and non-academia capacities (n = 69), which underscores the importance of academic capacity as perceived by faculty members. By contrast, external professionals were considered more appropriate for entrepreneurial capacity (n = 49).

These outcomes show that faculty members acknowledge the importance of training PhD students for both academic and non-academic positions, but more PhD supervisors considered academic training as their primary responsibility. While considering entrepreneurial capacity building relatively less important, they associated the responsibility for training this capacity to external professionals.

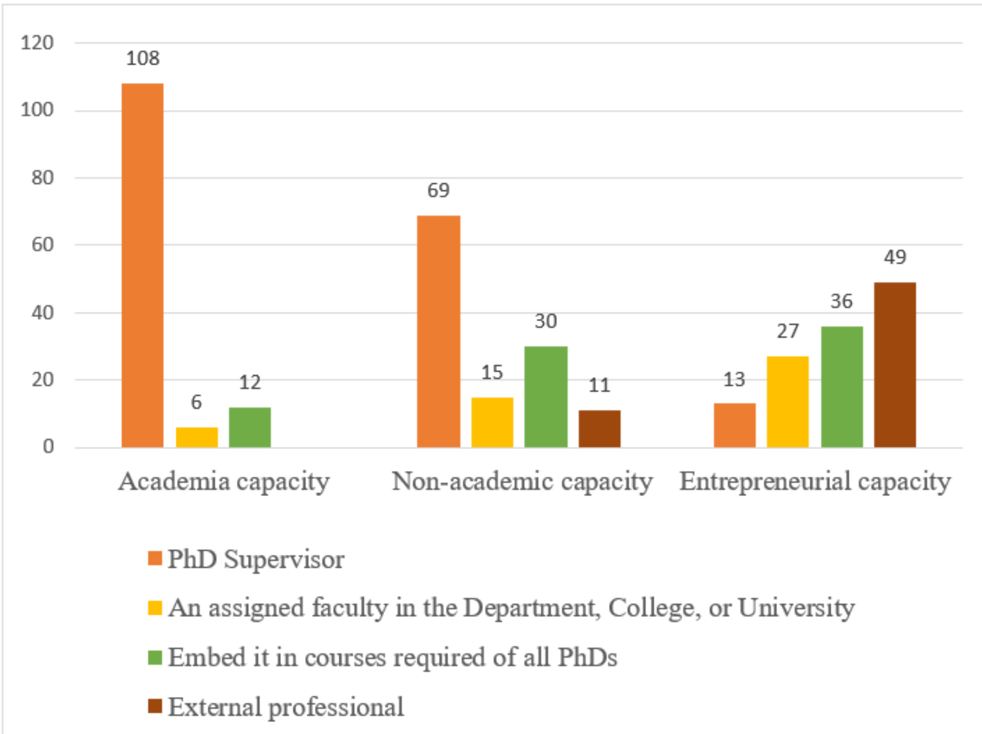

Fig. 5. Faculty's views on who should be mainly responsible for training doctoral students with the capabilities needed for academic, non-academic and entrepreneurship careers.

In summary, faculty members recognized their multifaceted responsibilities for the training of doctoral students. No single role dominated, with the largest proportion (22%) emphasizing the role of mentors and the smallest proportion (17%) on course instructors. The main training objectives included developing advanced research expertise (34%), preparing PhD graduates for success in academia (30%), and equipping students with skills valued by industry (29%). In addition to the mentioned choices, faculty stressed the importance of nurturing intellectual skills such as critical thinking, along with professional skills like communication and problem-solving, as integral for achieving the stated objectives. The emphasis on academic and non-academic capacity building was similar, while entrepreneurial capacity was considered less important. The findings also highlighted faculty members' recognition of stakeholders responsible for training, with PhD supervisors being the main stakeholders for both academic and non-academic capacities, while external professionals were seen as more responsible for entrepreneurial capacity.

4.3. Challenges and resources

To establish the impediments or challenges that the faculty members encountered to fulfill the doctoral training objectives, participants were asked to rate each challenge. The choices of challenges included: (i) insufficient career development resources at the university, (ii) difficulty in aligning the existing academic training expectations with students' career goals, (iii) limited access to industry-specific knowledge or expertise, (iv) challenges in teaching practical career skills, (v) balancing academic research and students' career readiness, (vi) lack of mentorship opportunities for students, and (vii) limited exposure to real-world industry experiences. Then, participants were asked to rate the challenge levels for each of these items on a scale of 1 to 5, where 1 represented the lowest level and 5 represented the highest level of challenge. The outcomes in figure 6 illustrate that among the six out of seven impediments faced by faculty members, the 3rd-level challenges constitute the largest proportion. However, for the impediment related to limited access to industry-specific knowledge or expertise, the largest proportion of faculty feel this category as a level 4 challenge. This feedback suggests that faculty members perceive this particular challenge as relatively more difficult to overcome than other impediments. Moreover, the findings from follow up open ended questions about additional impediments or challenges revealed that limited funding, lack of "pipeline leading to industry jobs," and "insufficient institutional recognition of the value of foundational strength" such as problem-solving and critical thinking skills hindered the cultivation of a successful doctoral training.

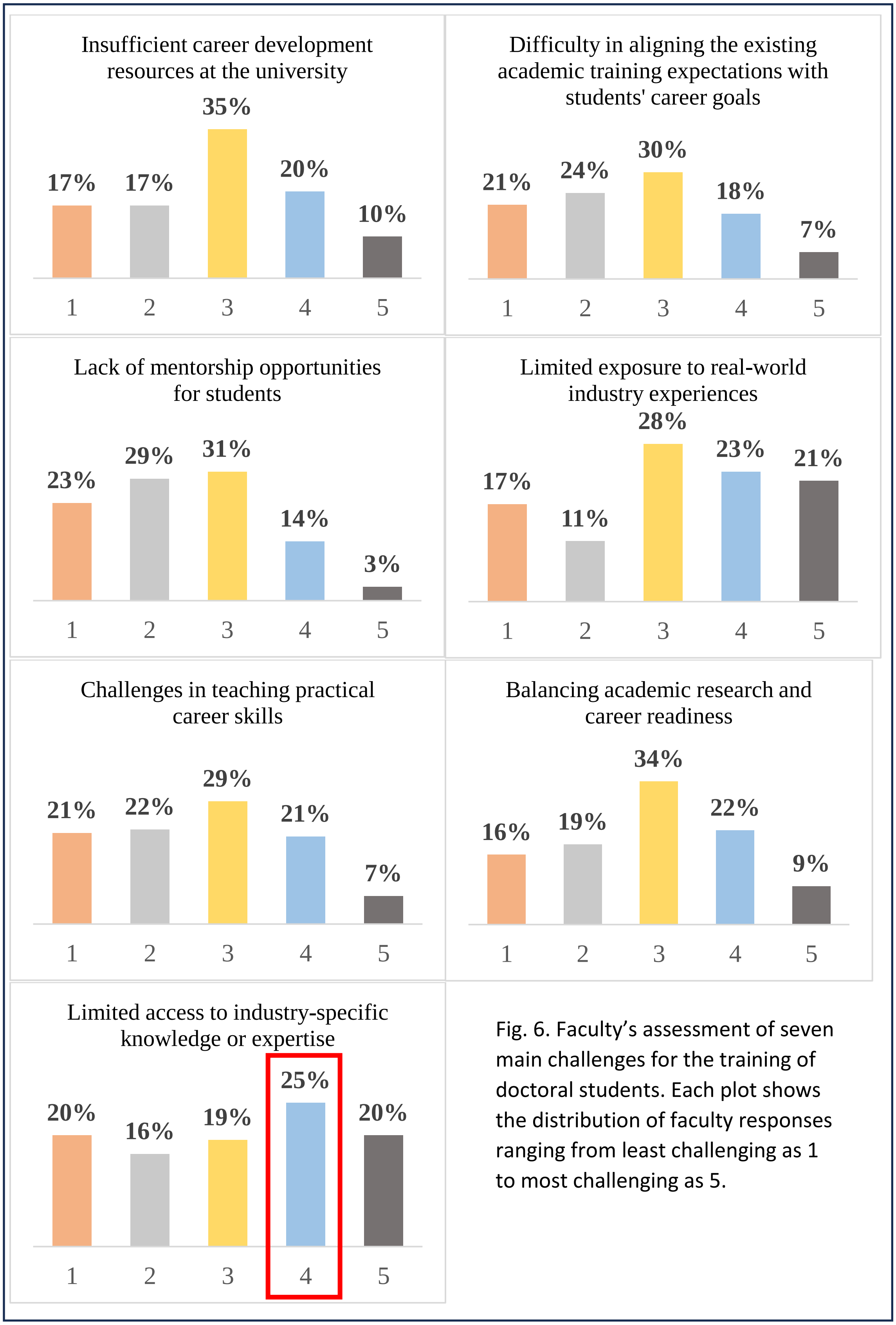

Fig. 6. Faculty's assessment of seven main challenges for the training of doctoral students. Each plot shows the distribution of faculty responses ranging from least challenging as 1 to most challenging as 5.

To identify the resources that would be helpful for overcoming the identified challenges, participants were asked to rate each of 11 resources from 'Very helpful' to 'Not helpful at all.' Among these resources (which included Career Development Programs, Formal Mentorship Programs, Industry Internships, Professional Networking Events, Curriculum Integration, Career Counseling Services, Cross-disciplinary Collaboration, Faculty Development, Alumni Engagement, Industry Research Collaborations, and Academic-Industry Forums), only two resources, Industry Internships, and Industry Research Collaborations, stood out as 'Very helpful' (see Fig. 7). This finding reveals that faculty are interested in building stronger ties to industry but are not able to realize them. For the remaining nine resources, eight of them were ranked as 'Helpful' in the largest proportion, whereas one resource, Curriculum Integration, was considered 'Moderately helpful' by the largest fraction of faculty.

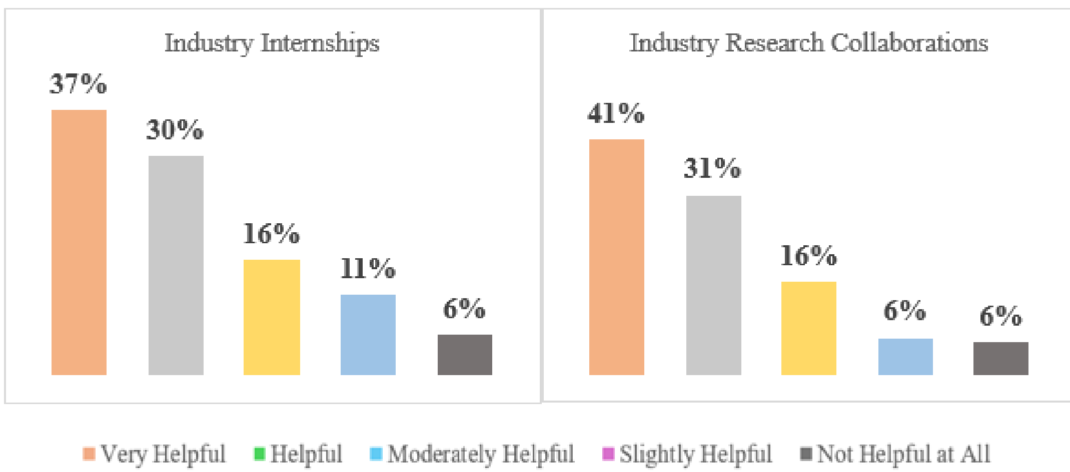

Fig. 7. Faculty's perceptions of helpfulness of Industry Internship and Industry Research Collaborations for the training of their doctoral students.

When asked about additional resources that might be helpful but not listed, faculty members mentioned a range of resources, including 'fundamental research training,' 'engaging local businesses and faculty startups,' 'taking classes beyond the ones directly related to one's research,' and 'training in taking care of students' physical and mental health, mindfulness, scientific writing, oral communication, and healthy interpersonal interaction communication.' Thus, the faculty members acknowledge that resources both within and outside the academic realm are needed to support doctoral training.

In short, limited access to industry-specific knowledge was perceived as a significant obstacle. Follow-up and answers to open-ended questions revealed additional challenges such as limited funding and insufficient institutional recognition. Regarding resources, Industry Internships and Industry Research Collaborations were recognized as 'Very helpful,' indicating a desire for stronger ties to industry. Other resources were generally considered 'Helpful,' with Curriculum Integration ranked as 'Moderately helpful.' In addition, the faculty members emphasized the need for a more holistic approach, including fundamental research training, engagement with local businesses and faculty startups, diverse coursework, and training in students' physical and mental well-being.

4.4. Skills and trainings

As for the question about the importance of qualities or skills besides subject matter expertise — such as effective communication, learning agility, collaboration, time management, ethics and research integrity, analytics (e.g., data science/statistics), project management, and critical thinking — faculty members were asked to rate from 'very important' to 'not important at all.' The results showed that 'very important' is the largest proportion for all qualities or skills. Additionally, faculty members mentioned various skills that they also consider important, including writing, marketing, hands-on experiences, entrepreneurial skills, networking, self-assessment, and independent research skills.

When asked if they would like to encourage collaborative research between their PhD students and non-academic partners (e.g., an industrial lab), 78% of the participants provided a positive answer (see Fig. 8). It is noteworthy that their positive answers often came with certain conditions. For instance, many faculty members indicated the necessity of grants or funding from industrial partners during collaboration. Some other faculty members pointed out that collaborations should be conducted without interrupting students' growth in research and publication. Some faculty members endorsed collaboration as they have been pursuing with industry and will continue to do so.

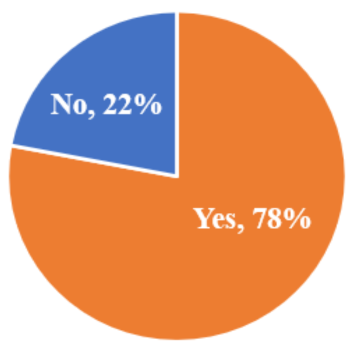

Fig. 8. Proportion of agreement on encouraging collaborative research between PhD students and non-academic partners

It is also noted that even if supporting collaboration, the faculty indicated a need for institutional support to establish and maintain connections. One faculty member mentioned, 'The University should facilitate. A tenure-track faculty has 100 hats to wear already. We should not be asked to act as a liaison.' Moreover, many faculty members mentioned that they were still learning how to start and manage such collaborations. One stated, “I would love to, but honestly, I don't really know how to approach that. I have never done it in my own research.” Some suggest national labs (e.g., NIST) can be good partners in making these connections, as well as department alumni. Others also indicated, “I would love for my students to engage in collaborative research experiences with industry, but the challenge is finding a synergistic match.”

As for the faculty members who did not see value in encouraging collaborative research, the main reason was their concern about non-academic partners. For instance, one faculty member mentioned that “R&D groups tend to limit or discourage publication and focus more on development than ideas,” which could hinder the training and profile of doctoral students. Others expressed concerns about whether industrial partners would be interested in collaborating “on projects that have zero practical or economic applications.” In addition, one participant indicated that “intellectual property issues are the biggest obstacle in establishing academic-industry collaboration.” Nevertheless, there are other issues that discourage faculty members from engaging in collaborative research with non-academic partners. These pertain to the highly theoretical nature of their research, or their belief that doctoral training should focus on fundamental research without any consideration of its usefulness to society at large. Besides, they were concerned about their students’ limited time, which would be further reduced by encouraging them to engage in collaborative efforts. In summary, faculty members generally have a positive attitude towards establishing and maintaining collaborative connections with industry. Apart from those already engaged, most other faculty members appeared interested and eager to secure more resources and institutional support to initiate/enhance their collaborations.

To get further insight into the origin of differences in faculty responses, we separated the data into two groups depending on whether they belonged to a discipline identified as curiosity-driven (CD) or use-inspired (UI). Conventionally, these groups of faculty members would have their ‘home’ in the College of Arts and Sciences or the College of Engineering and Applied Sciences, respectively. Figure 9 shows that although the majority of faculty in both groups favored encouragement of collaboration with industry, a notably higher fraction of faculty members from the UI group (83%) endorsed the idea compared to that of the CD group (69%). This finding indicates that the disciplinary focus of faculty members’ research does impact their perceptions about cultivating PhD students’ connections with non-academic fields.

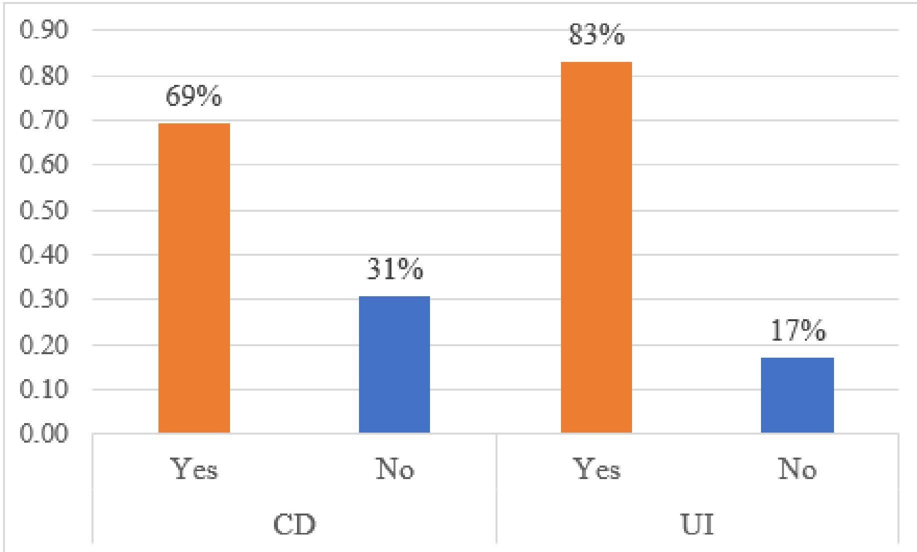

Fig. 9. Proportion of agreement on encouraging collaborative research between PhD students and non-academic partners by CD or UI group.

Regarding the question about to what extent do faculty members believe they should foster both academic and industrial experience in PhD students, only a little over quarter (27%) support it strongly, responding 'To a great extent' (see Fig. 10). The largest proportion feels moderately about it (30%), followed by 25% choosing 'Quite a bit', 14% 'Slightly' and 4% 'Not at all'. These results indicate that the majority of faculty members recognize the importance of offering both academic and industrial experiences as part of doctoral training.

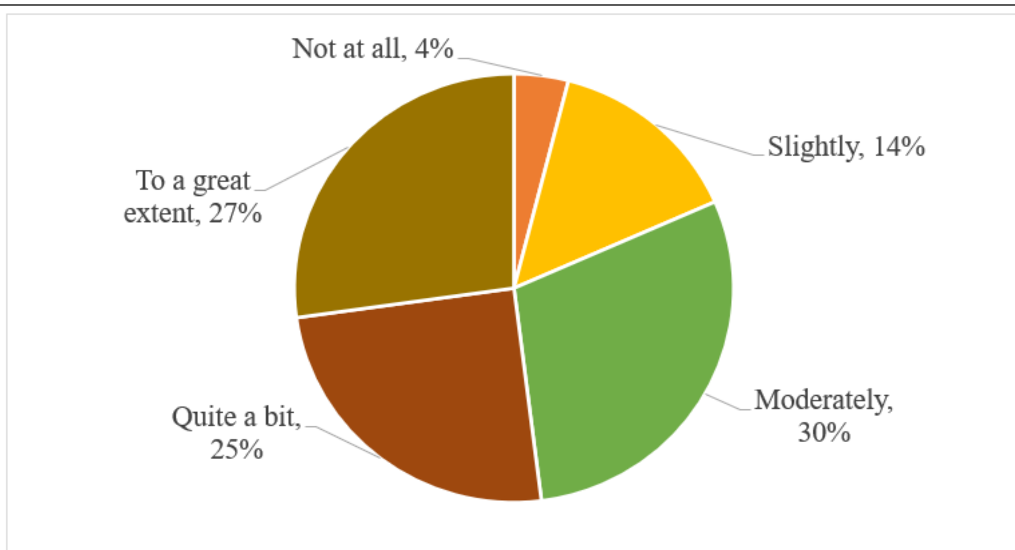

Fig. 10. Proportion of belief on whether faculty should foster both academic and industrial experiences as part of doctoral training.

For the faculty members who selected 'To a great extent' and 'Quite a bit' in support of collaboration with non-academic institutions,' their rationale mainly consists of three reasons. The first reason pertains to the fact that most of their current doctoral students intend to work in the industry after graduation, and they feel responsible to address those needs. As one faculty member mentioned, "Faculty should create opportunities for students to engage with the industry if that is their career goal." The second reason is related to the nature of their fields, as some fields require a strong industrial connection to progress in the research realm. For instance, one participant indicated, "CS (computer science) researchers need to have connections with the real world, and the advisor has the primary responsibility to facilitate that." Other faculty members from applied physics and chemical engineering also emphasized similar ideas. The third reason is from their perspective about mentorship. They consider it their responsibility to train a doctoral student for multiple career options since "holistic development is a major key to success for the student." This idea echoes with many other faculty members who state, "I consider it my responsibility to set my doctoral students on a fulfilling career path and not leave them high and dry after graduation." Therefore, they think cultivating both academic and industrial development is vital, especially if there is common ground— "I feel it's important to foster both the academic and the industrial path, focusing on the skills that overlap the most."

As for the participants who selected 'Moderately' for their response, they provided two broad rationales. The first rationale originates from the limitations of the faculty and institution. More specifically, as the participants disclosed, "many faculty members have very limited industry experience themselves," which makes establishing industrial connections challenging. Some other faculty members indicated limited resources that make industrial connections challenging, stating, "we receive little support for fostering industry experience' since it 'requires long-term vision on their part." Additionally, faculty members are calling for institutional support, expressing that "faculty would benefit greatly from a network of industry relationships maintained by the university." They also suggested that "industry affiliate organizations and annual industry visit days would be a great way to foster these relationships." The second rationale concerns their perception of students' goals. One faculty member mentioned, "it depends very much on the individual student and their interests and goals. Not all students need academic development. Not all students need industry development," which explains why they consider either academic or industry focus would be fine for training their doctoral students.

As for the faculty members who selected 'Slightly' for the response, the main rationales include their beliefs about doctoral training and their personal connections with the industry. Some participants stated that their job "as faculty is to train students in research," and they "should be training rigorous researchers who will take roles in academic environments and become thought leaders." Some other faculty members indicated that "most faculty are not trained to mentor students for the industry in their field, so this expectation is unreasonable for the faculty that we have on hand." They also mentioned having limited resources and time to establish industrial connections.

Lastly, for the small fraction of faculty members that responded, 'Not at all', the main reason is the nature of their area of expertise. For instance, some participants provided the fields they are working in, which include pure math and astrophysics, which have limited industrial applications, and it is possible for their students only to pursue a purely theoretical academic career. Therefore, they do not think it is necessary to encourage both experiences.

To examine the faculty's support for partnership with industry, we further categorized the responses by their disciplinary background either as CD (curiosity-driven) or UI (user-inspired) (see Fig. 11). The results show that faculty members from the UI group have higher percentages in the selections of 'To a great extent,' 'Quite a bit,' and 'Moderately,' than the CD group. In contrast, they have lower percentages in 'Slightly' and 'Not at all' selections. These outcomes resonate with the aforementioned findings revealed in Figure 9, indicating that when faculty members' research discipline is more use-inspired, they tend to support non-academic experiences along with academic experiences.

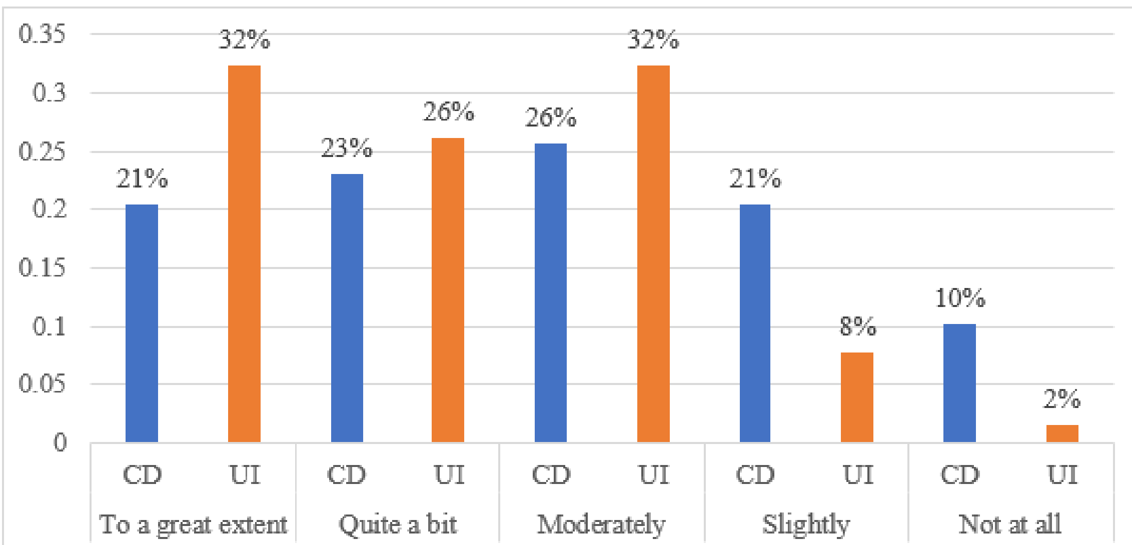

Fig. 11. Proportion of belief on whether faculty should foster both academic and industrial experiences as part of doctoral training categorized by CD and UI group.

Overall, the results indicate a consensus among faculty members on the importance of skills such as effective communication, learning agility, and project management. Whereas 78% of faculty express a positive inclination towards encouraging collaborative research with non-academic partners, they have expressed concerns including the need for funding, potential interruptions to students' research, and the requirement of institutional support. Regarding fostering both academic and industrial experiences, the majority of faculty members (85%) acknowledge its importance, but for varying reasons, ranging from meeting students' career goals to the nature of research fields. Faculty members from the UI group exhibit a higher proportion of agreement in fostering bonds with non-academic fields than the CD group, with more selections “To a great extent,” “Quite a bit” and “Moderately.” However, challenges such as faculty limitations, resource constraints, and differing student goals contribute to nuanced responses, demonstrating the complex considerations faculty members must navigate in shaping doctoral training experiences.

<u>4.5. Unstructured comments</u>

The last question in the survey asked participants to provide additional information that they believed could enhance doctoral training. Two themes emerged from their responses. The first theme pertains to the refinement of academic course plans. For instance, one faculty member highlighted the need for a revision in academic coursework to incorporate more relevant problem-solving, data analytics, and writing skills. This sentiment aligns with another suggestion emphasizing that academic courses often focus excessively on “technical knowledge rather than broad career skills.” The recommendation was to introduce a few well-designed career-related courses. The rationale behind these suggestions is that a successful doctoral mentee should possess robust analytical and critical thinking skills. These skills, as mentioned by participants, are essential for navigating various opportunities beyond the Ph.D., both in academia and industry. Strengthening these skills is perceived as the most “crucial set of abilities required for a successful transition to any field or industry”. Additionally, participants suggested that mentors should exert “more effort in sending students to conferences and workshops to facilitate networking and to enhance their understanding of industry opportunities.”

The second theme centers around institutional support. Specifically, participants emphasized the need for universities to streamline the process of signing collaboration agreements with industrial partners, suggesting that the current system could be made more efficient. Further, concerns were raised about the handling of Teaching Assistant (TA) assignments, highlighting that the current practice of managing them on an annual basis poses challenges for departments seeking to make multi-year commitments. This situation impacts various aspects, such as doctoral students' career plans in the longer term. Lastly, participants expressed a desire for “greater recognition of individual development plans (IDPs) by their departments” and emphasized the importance of the university “valuing mentorship in professional development in a broader context.”

5. Discussion and implications of results

This four-part anonymous survey of faculty members from 13 academic departments at our university has yielded several expected as well as some unexpected insights about their perspectives regarding doctoral training. The 125 respondents represented eight departments from the College of Engineering and Applied Sciences that would be conventionally considered pursuing use-inspired (UI) research, and five departments from the College of Arts and Sciences whose faculty would be typically viewed as pursuing curiosity-driven (CD) research. We expect that these results and their analysis, which are summarized below into four parts, would be particularly valuable to Ph.D. granting institutions that are interested in aligning their STEM doctoral training with the expectation of future employers.

Firstly, the findings highlight the diverse roles that the faculty members play in training doctoral students, with a recognition that no single role dominates. The faculty place a strong and comparable emphasis on both academic and non-academic capacity building, which underscores the importance of preparing students for various career paths. The findings further suggest that whereas entrepreneurial capacity is considered less important, there is a recognition of the need for external professionals to play a role to support the training of students who want to pursue this career path, which highlights the need for a holistic and adaptable training approach to meet the diverse needs of doctoral students. Additionally, the emphasis on nurturing intellectual and professional skills beyond the specified objectives underscores the comprehensive approach faculty members envision for doctoral training.

Secondly, the limited access to industry-specific knowledge is perceived as a significant impediment for preparing the students for jobs in industry. The majority of faculty emphasize the need to address this challenge for effective doctoral training. The recognition of Industry Internships and Industry Research Collaborations as 'Very helpful' indicates a strong desire for stronger ties with industry. These feedback from the faculty call for a more inclusive PhD training plan, including fundamental research training, engagement with local businesses, and training in students' mental well-being; they underscore the need for a comprehensive strategy to overcome the identified challenges. In addition, the results also reveal that faculty members face substantial challenges establishing relationships with suitable industry partners. Thus, for enhancing doctoral training there is a need for a multi-faceted training approach, including industry collaboration and a broader range of resources for both the students and faculty members.

Thirdly, the findings indicate a consensus among faculty members on providing certain non-technical skills and encouraging collaborative research with non-academic partners. As one might have expected, faculty members from the UI disciplines tended to encourage more non-academic experiences than their peers in the CD group. However, they also expressed concerns about funding, potential disruptions, and the need for institutional support that would need to be addressed to establish collaborative efforts. The nuanced responses regarding the importance of fostering both academic and industrial experiences underscore the complexity of balancing different PhD training goals and corresponding constraints. Moreover, considering that UI disciplines and CD disciplines inherently differ in their research foci, it is essential to account for these variations when designing or refining doctoral programs within each discipline. Typically, a given discipline would have both UI and CD components, but their relative emphasis may vary greatly from one discipline to the next. In all cases, the training of students should be commensurate with the prospects of their career plans and expectations of their potential employers. Thus, for instance, within UI-dominated disciplines, there should be a greater emphasis on providing resources for establishing industrial connections.

Lastly, the findings highlight the importance of refining academic course plans and institutional support for effective doctoral training. The emphasis on incorporating problem-solving, data analytics, and writing skills into coursework reflects a commitment to aligning academic training with the broader skills needed for diverse career paths. The need for enhanced recognition of individual development plans underscores the importance of adopting a personalized and supportive approach to mentorship for doctoral students and designing professional development for faculty members.

In conclusion, the survey emphasizes the need for a holistic and adaptable approach to doctoral training, considering diverse roles, challenges, and the importance of industry collaboration. The findings call for a more comprehensive strategy to meet the evolving needs of PhD students and faculty members. The present conclusions are based on faculty perspectives of their roles in doctoral training. Equally important will be an analysis of the perspectives and expectations of the students as well as non-academic employers who have called for a change in the current modes of training [6].

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9. Appendix

Faculty Perspectives on Their Role in the Training of STEM Doctoral Students

Introduction

Thank you for participating in this survey. Its purpose is to gather your perspective as a professor providing doctoral training to PhD students. As highlighted in this recent article in Nature , there is a pressing need to reform doctoral training. It is imploring higher education institutions to equip PhD graduates to become successful in whatever career path they choose upon graduation (academia, industry, national labs, healthcare organizations, government, etc.). Ahead of this article, in 2020 Lehigh established Pasteur Partners PhD (P3) track for STEM PhDs to meet these expectations, and further enhancements are planned in the strategic plan. Your feedback through this survey will contribute to a better understanding of the challenges, opportunities, and practices related to doctoral training and how to improve it further.

Roles and Responsibilities

1. How would you identify your primary role(s) in the doctoral training of PhD students in this academic year? (Check all that apply)

- Mentor
- Instructor of graduate courses
- Academic advisor
- Research supervisor providing financial support
- Dissertation committee member

Other (please specify): ________

2. What do you consider the main objectives of doctoral graduate training in your field? (Check all that apply)

[ ] Developing advanced research expertise in the discipline.

[ ] Preparing PhD graduates to become successful in academia (UG/Grad institutions).

[ ] Training PhD graduates to become researchers with skills that are valued by industry.

[ ] Preparing to become an entrepreneur.

Other (please specify): _______

3. The following questions is about the main objectives of doctoral training. For questions 2.1-2.3, please indicate your perception of their relative importance and the stakeholder you believe should be responsible for providing the specified training. For questions 2.4 and 2.5, please select all that apply:

3.1. Developing PhD students' abilities for careers in academia.

(a). Extremely Important (b). Very Important (c). Important (d). Slightly Important (e). Not Important

The stakeholder who should be primarily responsible for providing the training:

(a). PhD Supervisor, (b). An assigned faculty in the Department, College, or University,

(c). Embed it in courses required of all PhDs, (d). External professional.

3.2. Training PhD students for non-academic positions, such as researchers in private companies, national labs, defense organizations, healthcare, etc.

(a). Extremely Important (b). Very Important (c). Important (d). Slightly Important (e). Not Important

The stakeholder who should be primarily responsible for providing the training):

(a). PhD Supervisor, (b). An assigned faculty in the Department, College, or University,

(c). Embed it in courses required of all PhDs, (d). External professional.

3.3. Developing PhD students' entrepreneurial capacity.

(a). Extremely Important (b). Very Important (c). Important (d). Slightly Important (e). Not Important

The stakeholder who should be primarily responsible for providing the support:

(a). PhD Supervisor, (b). An assigned faculty in the Department, College, or University,

(c). Embed it in courses required of all PhDs, (d). External professional.

Challenges and Resources

4. What impediments or challenges have you encountered while striving to fulfill the doctoral training objectives you indicated above? (Check all that apply)

a) Insufficient career development resources at the university
b) Difficulty in aligning the existing academic training expectations with student's career goals
c) Lack of mentorship opportunities for students
d) Limited exposure to real-world industry experiences
e) Challenges in teaching practical career skills
f) Limited access to industry-specific knowledge or expertise
g) Struggles in integrating career-focused trainings into academic programs
h) Balancing academic research and career readiness

Other (please specify): _______

5. What resources do you believe would be helpful for you to overcome the above identified challenges? (Check all that apply)

a) Career Development Programs
b) Formal Mentorship Programs
c) Industry Internships
d) Professional Networking Events
e) Curriculum Integration
f) Career Counseling Services
g) Cross-disciplinary Collaboration
h) Faculty Development
i) Alumni Engagement
j) Industry Research Collaborations
k) Academic-Industry Forums

Other (please specify): _______

Skills and trainings

6. In your opinion, what are the essential qualities or skills, besides subject matter expertise, that a successful PhD student should possess by the time they graduate?

a) Effective communication
b) Learning agility, openness to collaboration, cross-discipline interest, broad perspective
c) People skills, teamwork
d) Time management, rapid and practical problem solving, innovating in real time
e) Ethics, lab safety, research integrity

f) Analytics, data science/statistics
g) Business acumen
h) Project management, government regulations
i) Intellectual property issues
j) Economic analysis
k) Critical, independent thinking
l) Other (please specify): ________

7. To what extent do you believe a faculty like yourself should foster both academic and industrial experience development in PhD students? Please explain your choice.

(a). Not at all, (b). Slightly, (c). Moderately, (d). Quite a bit, (e). To a great extent

Please explain your choice: _______

8. Do you or would you like to encourage collaborative research between your PhD students and non-academic (e.g. industrial) partners?

If yes, how do you or expect to facilitate such collaborations?

If not, please briefly explain your rationale.

9. Is there any additional information or insights you would like to share about your experiences in providing doctoral training to PhD students?