The Characteristics and Reflections of Engineering Doctorate Training System in China

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Abstract:

The doctoral education in engineering has emerged to cultivate adept leaders in applied engineering technology, contributing to the establishment of an innovative nation. The engineering doctoral education in China has evolved over a decade. This study analyzes doctoral degrees in engineering at four Chinese universities, examining the current state of engineering doctoral education across various dimensions, including training objectives, admission criteria, curriculum design, pedagogical approaches, and graduation requirements. Overall, China's engineering doctoral training system exhibits a gradual improvement, concomitant with a progressive expansion in scale. Looking forward, it is imperative to broaden the spectrum of enrollment, enhance the theoretical foundation of engineering doctoral students, fortify quality control measures, and implement an elimination mechanism. This research contributes to a nuanced understanding of the developmental trajectory of engineering doctoral education in China.

Keywords: professional doctorate in engineering, China, graduate education, training system

1. Introduction

Since 1990, a novel category of advanced degrees known as "professional practice doctorates " has proliferated within the landscape of higher education in the United States and beyond. Alternatively labeled as "work-based doctorates," these degrees are research-oriented but distinguish themselves from Ph.D. programs by centering their research on pertinent, applied issues or problems rooted in a candidate's workplace or professional practice, rather than an academic research question (Johnson, D., 2005). This research aims to offer valuable insights to sponsoring organizations of professional practice doctorates and contribute to the knowledge base within the respective field of practice. Recognized as the pinnacle of professional extension, the professional practice doctorate is designed to train senior applied talents capable of making significant and original contributions to practices of public value, thereby positioning candidates as influential figures within the professional practice community (Costley, C., & Lester, S., 2012; Lester, S., 2004). One specific manifestation of the professional practice doctorate is the Engineering Doctorate (D.Eng), which represents a distinctive professional practice doctoral degree. The establishment and evolution of the D.Eng are intricately linked to the dynamics of social and economic development.

As science and technology progressively emerge as the cornerstone of economic development, the pace at which technology translates into productivity accelerates, concomitant with a shortened product cycle. Enterprises find themselves compelled to integrate design, development, sales, and management , thereby imposing heightened demands on enterprise engineers. These professionals are not only required to possess expertise in specialized technical domains but must also demonstrate the ability to synthesize technology, societal considerations, and market dynamics, assuming roles such as managers, chief engineers, and designers. In response to the evolving requirements of the market economy, Harvard University strategically positioned the training of certain doctoral personnel as akin to senior professionals within the workplace, although, notably, it refrained from designating this training as a distinct degree at that juncture. Until 1965, the American Association of Engineering Inspectors unequivocally advocated for the establishment of engineering doctoral education programs, thus inaugurating the era in which universities could offer the Engineering Doctorate. In the latter half of the 20th century, the fruition of efforts invested in training engineering doctoral candidates became evident in the United States. Subsequently, Germany, France, Britain, and other nations emulated this trajectory by instituting engineering doctoral training programs and establishing dedicated professional locations for engineering doctors. As the 20th century drew to a close, the United States emerged with notable achievements in engineering doctoral training, prompting Germany, France, Britain, and other countries to follow suit, instituting engineering doctoral training initiatives and creating specialized professional programs. For instance, the United Kingdom introduced the Engineering Doctorate (D.Eng) in 1992. In 1993, the document titled 'Realizing Our Potential: Strategy for Science, Engineering & Technology' advocated for the prioritization of professional practice degrees, particularly the Engineering Doctorate, within universities and academic institutions. The emphasis was placed on elevating the societal acknowledgment of engineering doctorates. Subsequently, in 2012, the UK Engineering Council issued a statement stipulating that obtaining a D.Eng was a requisite academic qualification for registration as a Chartered Engineer. This measure further bolstered the societal recognition of D.Eng, augmenting the stature and identity of engineering doctoral education. (Association of Engineering Doctorates 2012).

The primary objective of the D.Eng is to nurture highly skilled professionals with an application-oriented focus, capable of translating scientific and technological advancements into productive forces. These individuals are adept at driving technological and engineering innovation, thereby contributing to the progress of engineering construction (Chou & Zhang, 2004). The D.Eng strategically aligns the educational endeavors of institutions with the imperative needs of national development. The advancement of doctoral education in engineering holds multifaceted benefits. Not only does it contribute to the enhancement of professional degree standards within higher education, fostering a more refined degree awarding system, but it also plays a pivotal role in cultivating versatile and applied engineering talents. These talents, in turn, contribute significantly to scientific and technological innovation and the successful execution of major projects. In summary, the interplay of internal and external factors within higher education synergistically propels the evolution of the professional degree of the engineering doctor. The cultivation of engineering doctoral candidates represents a pivotal strategy in proactively contributing to the establishment of an innovative nation. It concurrently serves as a focal point for reforms in degree and postgraduate education. Despite the relatively recent inception of the D.Eng., its significance has garnered widespread recognition and is currently experiencing robust momentum in development across nations.

This article analyzes the current situation of the engineering doctoral education system in China. The purpose of this paper is to present the characteristics of the engineering doctoral education model and provide suggestions for better training of engineering doctoral professionals in China.

1.1 The development of engineering doctorate in China

China initiated the implementation of professional practice degrees in the 1980s, driven by the dynamics of social and economic development. In 1998, the government took a proactive step by establishing professional master's degrees specifically within the engineering domain. This initiative aimed to train applied master's students in engineering and concurrently established a steering committee to oversee and guide these endeavors.

The 21st century heralds an era characterized by scientific and technological innovation driving economic development, marking a shift from a labor-intensive to a technology-intensive economy. Enterprises find themselves in pressing need of a cadre of high-level interdisciplinary technical professionals equipped with innovative, organizational, and managerial capabilities. These professionals must not only navigate complex engineering challenges but also proactively contribute to, if not lead, the transformation and innovation of enterprise technology and project development. Crucially, these individuals should possess a balance of academic innovation and practical application transformation capabilities.

The shift in societal demand is most conspicuous in the evolving direction of university talent training. Against the backdrop of the economic "new normal" and the implementation of strategic initiatives such as "Made in China 2025," the "Belt and Road Initiative," the construction of the "Guangdong-Hong Kong-Macao Greater Bay Area," and "Healthy China 2030," there is an acute demand in China for high-level talents with a robust theoretical foundation in technology and adept practical skills with strong application capabilities. However, the traditional graduate personnel training structure, predominantly academically oriented, falls short of fully aligning with the strategic developmental needs of the nation at the current stage.

Hence, the imperative to recalibrate the graduate degree structure and proactively advance professional graduate education has emerged as an inexorable trajectory in the endeavor to foster innovation in China. This strategic shift represents a compelling choice for graduate education, aligning itself with the overarching goals of supporting national economic development and societal progress. The conventional academic doctoral degree, designed primarily to cultivate talent for future basic research endeavors, confronts limitations manifested in a perceptible disparity between the practical competencies of doctoral graduates and the exigencies of societal demands.

In response to this context, the state introduced the professional degree of Doctor of Engineering. In 2011, the Academic Degrees Committee of The State Council critically deliberated and ratified the "Program for the Establishment of Professional Degrees of Engineering Doctors." Subsequently, approval was granted to 25 institutions to spearhead the pilot initiatives for recruiting and training engineering doctors. This pivotal step laid the initial groundwork for the nascent development of engineering doctoral education in China. In 2012, the designated pilot universities officially commenced the enrollment of students, with the initial cohort concentrated in four specialized fields: biomedicine, electronic information, advanced manufacturing, and energy and environmental protection. Subsequently, in 2013, the Ministry of Education and the Chinese Academy of Engineering issued the "General Standards for Excellent Engineer Education and Training Program." This directive established overarching standards for the cultivation of engineering doctoral talents, prioritizing the development of practical skills such as product design, development, and project research and development among engineering doctoral students.

In alignment with the broader objectives of deepening the reform of postgraduate education, enhancing China's training system for engineering and technical personnel, and cultivating leading talents in engineering and technology, a pivotal "Reform Plan for the Training Mode of Engineering Doctoral Graduate Students" was formulated in 2018. This plan aims to expand to 40 institutions and delineates explicit regulations pertaining to the training objectives, methodologies, enrollment criteria, as well as the knowledge, abilities, and qualities expected of engineering doctoral students. It also provides guidelines regarding dissertations and quality assurance measures. Following graduation, a substantial number of outstanding engineering doctoral students actively contribute to various national engineering and technology initiatives, playing a pivotal role in these endeavors.

2. Research Method

2.1 Analysis framework

The inception of the D.Engis a product of the intersection between traditional doctoral degrees and the evolving demands of contemporary societal development. Diverging from conventional academic doctoral degrees, the D Eng places greater emphasis on the practical application of theoretical knowledge to real engineering problems. Graduates typically possess hands-on experience in addressing practical engineering challenges.

The value of the D.Eng lies in the cultivation of professionals equipped with profound expertise and practical engineering experience to meet the high-level demands of the industrial sector for engineering professionals. This degree underscores practical application, career development, and leadership training, providing a more practice-oriented academic pathway for practitioners in the engineering domain. Crucially, distinct from traditional doctoral degrees (Zemelka, 2017), the D.Eng program holds dual objectives, namely expanding theoretical knowledge within the academic realm and elevating current practices within professional environments (Newton et.al, 2019). Admission requirements, curriculum structures, and outcomes of the D.Eng program may differ from those of traditional doctoral programs. As Loxley and Seery (2012) asserted, although both types of degree programs may contribute to creating new knowledge in the engineering industry, the D.Eng program is designed to bring about dual accomplishments for its graduates.

Although there are differences in the training models for professionals with an D.Eng and traditional doctoral education, the underlying foundation of the D.Eng remains centered on student development. Astin (1993) developed the I-E-O model for college student development, where inputs are defined as the characteristics of students upon initial enrollment; environment encompasses various elements such as programs, policies, faculty, peers, and educational experiences that students encounter; and outcomes refer to the characteristics of students after exposure to the environment. Drawing inspiration from this model and rooted in the essence of doctoral student training, this paper proposes that the establishment of the D.Eng program can be comprehensively understood through three dimensions: entrance, environment, and exit. Entrance pertains to the standards and requirements for admission to the D.Eng program, while environment addresses the training process for Engineering Doctoral candidates, encompassing training objectives, curriculum design, and training methods. Exit points to the graduation requirements for doctoral candidates . This study, based on the aforementioned indicators, analyzes the current status of talent cultivation in China's Engineering Doctoral Professional Degree, employing an implicit comparative perspective to scrutinize the distinctive features of talent cultivation in the D.Eng program.

2.2 Sampling

Tianjin University, Shanghai Jiao Tong University, Zhejiang University, and Xi'an Jiaotong University, renowned for their engineering disciplines, were selected as pilot universities for the professional doctoral degree in engineering when China initiated the program in 2011. By 2020, these four universities have established 5-7 degree-granting programs for the professional doctoral degree in engineering, covering disciplines such as electronic information, materials and chemical engineering, resources and environment, energy and power, civil engineering, and water conservancy. Aligned with the national development strategy and considering the profound changes in the current industry and the characteristics of future engineering and technological talents in China, these four universities actively research the training direction, objectives, pathways, and measures for graduate students pursuing professional doctoral degrees in engineering. This initiative aims to promote reforms and development in the education of professional doctoral degree students in engineering. Over the years of constructing doctoral programs, these universities have accumulated valuable experience and, to some extent, represent the current status and development trends in the cultivation of engineering doctoral students in China. Therefore, this study selects these four universities as typical representatives, aiming to explore the characteristics of the Chinese engineering doctoral education system through the practical training of doctoral students in engineering at these institutions.

3. Characteristics of the Engineering Doctoral Training Mode in China

3.1 Goal Setting: Emphasis on the cultivation of high-level applied talents

Training objectives play a crucial role in shaping the trajectory of engineering doctoral student training, serving as a rational foundation for the existence of engineering doctoral degrees. Examining the training goals established by the four institutions, universities strategically align the professional degree structure of the D.Engwith the imperatives of China's economic, social, and scientific-technological development. In doing so, they confront the actual engineering challenges prevalent in enterprises (industries), leveraging the unique characteristics of the Chinese social system. Grounded in a commitment to moral education as the cornerstone, the universities aim to foster and instill socialist core values, laying the groundwork for the cultivation of future leaders in engineering technology. The training objectives outlined by Zhejiang University and Tianjin University exhibit similarities, emphasizing the belief that an engineering doctor should possess a broad theoretical foundation and specialized knowledge. Furthermore, they should demonstrate proficiency in resolving practical engineering challenges, conducting research and development in engineering technology, as well as organizing and executing engineering technology projects. Xi'an Jiaotong University seeks to cultivate leaders in engineering technology innovation, fostering individuals with a combination of research and development skills alongside managerial capabilities. Shanghai Jiaotong University aspires to nurture engineering technology leaders endowed with enhanced comprehensive qualities, spanning engineering technology, management, and innovation consciousness. These leaders are expected to contribute creative achievements that advance industrial development and engineering technology progress. Simultaneously, it is emphasized that doctoral students should harbor a global vision and strategic thinking, with a focus on training future international engineering science and technology leaders.

Table.1 Training Objectives of Engineering Doctors in the Four Universities

University	Training Goal
Xi'an Jiaotong University	For enterprises, leveraging major national science and technology projects in conjunction with cutting-edge industry technologies and development trends, there is a strategic imperative to cultivate highly specialized talents with applied, interdisciplinary, and innovative capabilities in the domains of 'advanced manufacturing' and 'electronic and information engineering.' These talents are envisioned to emerge as leaders and facilitators in engineering technology innovation, embodying a fusion of high-level technological expertise and managerial proficiency.
Shanghai Jiaotong University	The Doctor of Engineering program is designed to cultivate leading talents in engineering technology with a global vision, strategic thinking, and enhanced comprehensive qualities. This is achieved through university-enterprise collaboration and by leveraging national major engineering projects.
Zhejiang University	The training in the field of the related engineering master program establishes a solid and comprehensive theoretical foundation, coupled with in-depth expertise in systematic knowledge. This equips individuals with the capability to address intricate engineering challenges, foster innovation in engineering technology, and demonstrate organizational proficiency in engineering research and development. Moreover, it cultivates a sense of high social responsibility among high-level engineering and technical personnel, laying the groundwork for the development of engineering technology talents.
Tianjin University	Education in the field of the relevant engineering master's program provides a robust and comprehensive theoretical foundation along with in-depth expertise in systematic knowledge. This training equips individuals to tackle complex engineering problems, drive innovation in engineering technology, and demonstrate organizational proficiency in engineering research and development. It also instills a strong sense of social responsibility among high-level engineering and technical personnel, thereby establishing the foundational framework for the cultivation of engineering technology talents.

3.2 Admission Criteria: Establish a 'dual threshold' comprising educational background and work experience

Shanghai Jiaotong University and Zhejiang University accept applicants with master's and bachelor's degrees but require master's degree holders to have a minimum of three years of work experience. Undergraduate graduates are mandated to possess over 6 years of work experience, while Zhejiang University, exclusively for bachelor's degree applicants, necessitates more than 8 years of work experience. Tianjin University and Xi'an Jiaotong University admit applicants with a master's degree or its equivalent but do not consider those with only a bachelor's degree. Tianjin University does not specify a minimum work experience requirement, but for applicants with the same academic standing as master's graduates, it is imperative to hold at least the title of associate high school or above and furnish evidence of relevant research achievements, such as two academic masterpieces published in university-recognized core journals or significant accomplishments in their work, with at least one being recognized at the provincial or ministerial level or above. Xi'an Jiaotong University mandates applicants to possess five or more years of practical experience in engineering technology or engineering management. For those with a master's degree equivalent, particularly outstanding engineering and technical personnel, over eight years of practical experience in engineering technology or engineering management is required.

In terms of professional background and practical expertise, Shanghai Jiaotong University mandates that applicants actively engage in research related to major national science and technology projects within their respective fields. Additionally, they should possess a robust theoretical foundation in engineering technology, coupled with substantial practical experience, and demonstrate leadership in overseeing significant engineering technology research projects. Enrollees at Zhejiang University typically hail from units involved in major and pivotal engineering projects within the engineering domain. They are expected to possess a sound theoretical grounding in engineering technology and exhibit strong practical capabilities. Tianjin University stipulates that applicants should be professionals in engineering technology or engineering management, equipped with a solid theoretical foundation in relevant fields of engineering technology, robust practical experience or potential, and the capacity to assume a technical leadership role in national key industries, major engineering projects, and strategic emerging industries. Prospective candidates applying to Xi'an Jiaotong University are expected to have a distinguished working background as high-level engineering and technical professionals. Currently, these candidates possess extensive practical experience in engineering and technology, accompanied by notable achievements in the domains of 'advanced manufacturing' or 'electronics and information.' In general, the admission criteria for engineering doctoral programs set high standards for academic qualifications, professional experience duration, and practical engineering expertise. Universities tend to preferentially admit individuals who have actively participated in national major science and technology special research programs, emphasizing the recruitment of core personnel. Moreover, some institutions are also focusing on the cultivation of full-time engineering doctoral students, encouraging the enrollment of recent master's graduates who are required to engage in engineering practice research during their master's program.

3.3 Curriculum: Implement a credit system to establish a modular curriculum framework

In terms of curriculum design, all four universities have adopted a credit system, requiring engineering doctoral candidates to accumulate a specified number of credits as a graduation requirement. The curriculum is structured through a combination of mandatory and elective courses, typically categorized into public foundational modules, professional modules, and practical professional modules.

The public foundational module encompasses courses on ideology and politics, English, and, in some cases, engineering management. Engineering doctoral candidates engage in ideological and political courses to foster self-management skills and develop the ability to apply dialectical materialism and historical materialism in critical thinking and problem-solving. Furthermore, engineering doctoral students, equipped with a solid understanding of China's national development policies and direction, can make informed policy decisions for significant national projects. This ensures that project construction aligns with the fundamental principles of China's social development, truly benefiting the public and enhancing the social impact of these projects. The professional module courses deliver in-depth theoretical knowledge and the latest advancements in the engineering field, adapting to the evolving landscape of engineering and changing societal needs (Xiao F et al., 2014).

The professional practice module aims to cultivate engineering talents capable of swiftly adapting to industrial environments while possessing innovative and practical abilities. This is achieved through thesis research intertwined with major national science and technology projects and significant enterprise research initiatives, hands-on professional training at university-enterprise joint training bases, and engagement in research, international exchange, and collaboration with foreign research institutions or reputable international companies.

Adhering to the principles of 'individualization, practicality, internationalization, and ordered structure,' Shanghai Jiaotong University categorizes the engineering doctoral program into five modules: public basic courses, professional basic courses, professional frontier courses, professional elective courses, and practical components. Students are mandated to complete a minimum of 16 credits.

Zhejiang University emphasizes the enhancement of technical innovation, organizational and leadership skills, and project management capabilities of engineering doctoral students, stipulating a total credit requirement of no less than 14, with at least 12 in coursework. The curriculum is tailored to the distinct learning approaches of full-time and part-time engineering doctoral students, addressing their specific needs. A part-time engineering PhD candidate is obligated to fulfill 6 credits in public courses (comprising 'Chinese Marxism and Contemporary,' 'Practical Communication English,' and 'Engineering Management') and a minimum of 6 credits in professional courses, encompassing at least 1 engineering technology frontier course. Recognizing the potential deficit in practical skills among full-time students, additional requirements include 2 credits for reading (practice) reports, in addition to public and mandatory courses. Simultaneously, the university offers supplementary courses designed for doctoral students that traverse training types or span across professional degree categories and fields.

Tianjin University mandates that engineering doctoral candidates must complete a minimum of 16 credits throughout their academic journey. This includes no less than 6 credits for core courses, a minimum of 3 credits for required courses, and at least 7 credits for elective courses. The obligatory curriculum features 2 credits dedicated to 'Chinese Marxism and Contemporary China' and 2 credits for management (leadership) courses provided by the Ministry of Management and Economics. Compulsory courses encompass practical components and academic reports (communication), while elective courses are exclusively offered by the college.

Xi'an Jiaotong University boasts a relatively more comprehensive course structure for the D.Eng, encompassing degree courses, elective courses, lectures, and professional practice. This curriculum spans professional foundation, professional technology, humanities and social sciences, economics, organizational management, law, and other relevant areas. The components of the training program encompass course learning, which includes lectures, professional practice involving international exchange, and dissertation completion, among others. A minimum of 13 credits is required, with at least 6 credits dedicated to mandatory courses, 15 credits allocated for professional practice, and an additional 2 credits for interim assessment. The engineering doctoral degree program is characterized by its comprehensiveness, cutting-edge nature, and interdisciplinary approach.

Analyzing the curriculum offerings across the four aforementioned institutions, it becomes evident that Xi'an Jiaotong University provides a broader spectrum of knowledge fields within its curriculum. This includes interdisciplinary courses designed for the development of well-rounded engineering doctoral candidates, with a particular emphasis on fostering the comprehensive qualities of these students. Recognizing that engineering projects should not solely focus on the technical aspects, the university adopts the principle of 'scientific humanism,' wherein human values take precedence. In this context, humanitarianism serves as the core principle, emphasizing the need for individuals to master science and technology rather than becoming subordinate to it. The Doctor of Engineering must approach every major project with a profound commitment to serving and benefiting the people, imposing elevated expectations on the humanistic qualities of engineering doctors. Ethical and moral education remains crucial for enhancing the cultural proficiency of engineering doctoral students. Furthermore, in comparison to the latest phase of educational reforms, the merits of engineering doctors extend beyond individual innovation and problem-solving skills. They must also possess strong management abilities to lead entire project teams, addressing society's demand for adept applied science and technology leaders. This underscores the importance of engineering doctoral course design, which should not only focus on developing the scientific and technological innovation and project development skills of engineering doctors but also emphasize the cultivation of their comprehensive qualities.

3.4 Training Method: Implementation of the 'dual mentor' system with personalized guidance

In the 2018 reform plan, it is suggested that the training of engineering doctors should embrace a university-enterprise cooperation model. This involves engaging experts with substantial industry experience as enterprise mentors and forming a mentor group in collaboration with academic tutors from the university. The purpose is to jointly guide the academic and practical endeavors of engineering doctoral candidates (Ministry of Education 2018).

Adhering to the stipulations of the reform plan, the four universities employ strategies such as university-enterprise collaboration, "double mentor" guidance, and personalized training. The emphasis on the practical proficiency of engineering doctors underscores the partnership between the university and the enterprise. Enterprises play a pivotal role in providing practical training grounds, research and development projects, and incubation centers for the transformation of achievements. The "double tutorial system" facilitates the effective application of theoretical advancements from universities to enterprise product development, achieving a harmonious integration of "production, learning, and research." This approach better aligns with the requirements of national economic and social development for high-level, multi-skilled talents. The term "double tutors" does not refer to having two mentors; instead, it signifies a mentorship team consisting of academic mentors from the university and practical mentors from the corporate sector. Academic mentors within the university typically are required to lead or engage in pertinent major national science and technology projects, while enterprise mentors should be distinguished experts in relevant fields holding regular positions in high-tech domains.

Adhering to the principle of 'leveraging strengths and addressing weaknesses,' the faculty team collaborates with graduate students to devise training plans that reflect personalized development, creating customized programs tailored to individual future needs. Different roles within the faculty team entail distinct responsibilities. Academic mentors participate in crafting course learning plans with graduate students and oversee and supervise their coursework, thereby enhancing the developmental trajectory of the students. External mentors primarily concentrate on directing students to enhance their practical operational skills, augmenting their practical cognitive abilities, and improving their adaptability to future professional settings. Presently, certain universities have adopted a collaborative training model, incorporating both domestic and international mentors, with a particular emphasis on cultivating international, high-caliber engineering professionals.

Shanghai Jiao Tong University engages tutors and engineering doctoral students in crafting the training plan, employing flexible arrangements for teaching and research. The execution of the training plan involves various methods such as discussions, exchanges, project collaboration, concentrated training, and learning. Zhejiang University implements a school-enterprise cooperative approach for training, utilizing joint guidance by the school-enterprise tutor group. The university invites experts from enterprises (industry) with extensive engineering practice experience as members of the tutor group. The training process encompasses coursework and dissertation work. Xi'an Jiaotong University's engineering doctoral program adopts a 'talent + project' training mode, incorporating innovative mechanisms like university-enterprise cooperation, collective guidance from tutor groups, personalized training, and joint domestic and international training. The tutor team for engineering doctoral students typically consists of 3-5 members, engaging in multidisciplinary cross-training and providing joint guidance. This team comprises campus, industry, and overseas instructors. Overseas tutors are expected to hold a Ph.D. and possess experience working in internationally acclaimed enterprises. The entire team of instructors collectively oversees guiding the selection of engineering doctoral thesis topics, scientific research activities, professional practice, mid-term assessments, dissertation writing, and defense.

3.5 Graduation Criteria: Emphasis on dissertation completion

The assessment of an engineering doctoral degree hinges on the successful completion of a doctoral dissertation. Aligned with the training objectives for engineering doctoral students, universities outline specific requirements for their doctoral candidates. Firstly, the dissertation of professional doctoral candidates in engineering should intricately connect with significant engineering projects in relevant fields and the practical engineering landscape of enterprises. Secondly, the research content of the paper should be closely tied to addressing major engineering technical challenges, contributing to enterprise technological progress, and facilitating industrial upgrading. This may involve research into new engineering technologies, significant engineering design, or the development of new products or devices. Ultimately, an engineering doctoral dissertation is expected to possess substantial engineering application value.

Shanghai Jiao Tong University allows for diverse formats in engineering doctoral dissertations; however, it mandates that these dissertations must showcase the contributions and creative accomplishments of engineering doctoral students in the exploration of major national science and technology projects. Additionally, they should demonstrate the ability to independently address significant practical challenges. The dissertation topic should be derived from engineering practice projects of paramount practical significance and application value. The assessment of the paper primarily focuses on the systematic presentation, advancement, and efficacy of the solutions proposed for major engineering challenges.

Xi'an Jiaotong University also specifies that dissertations can take various forms, including a comprehensive research dissertation, a design scheme and demonstration report for substantial engineering projects, or a technical dissertation rooted in the design of major engineering projects. It could also be a research report encompassing a series of research projects. Regardless of the chosen format, the graduation thesis must unequivocally represent the tangible contributions and creative accomplishments of the engineering doctor within the framework of an engineering practice project. To assess whether engineering doctoral students have truly acquired a profound understanding of the fundamental theories and specialized technical knowledge within their field. This evaluation should also gauge their capacity for core technology development, ongoing innovation research, and international competitiveness. Furthermore, it should appraise their ability to independently address significant engineering technical challenges.

Moreover, Shanghai Jiaotong University outlines specific criteria for the research accomplishments, recognition through scientific and technological awards, patent inventions, and project design reports by engineering doctoral students, all of which collectively serve as graduation requirements. Zhejiang University mandates that engineering doctoral theses must manifest innovative achievements in diverse forms, encompassing academic papers, invention patents, industry standards, science and technology accolades, and more. These outcomes should be pertinent to the dissertation content and achieved during the course of the degree. Evaluation of the engineering doctoral dissertation centers on its academic caliber, technological innovation, and societal and economic impact, with a particular emphasis on assessing its novelty and practicality.

4. Findings

Based on first-hand data from the earliest universities that established professional doctorates in engineering programs, this paper analyzes the current situation of engineering doctoral talent cultivation in China from five perspectives: admission criteria, training objectives, curriculum design, training methods, and graduation requirements.

We found that the current cultivation of engineering doctoral professional talents in China exhibits certain characteristics compared to traditional doctoral education: (1) In terms of enrollment, there is an emphasis on the diversity of sources, generally requiring candidates to have a certain amount of work experience, indicating a focus on enrolling part-time students for the D.Eng. (2) Regarding training objectives, attention is given to deepening the theoretical foundation and specialized knowledge of doctoral students, enhancing their ability to solve engineering problems and management skills, and emphasizing the cultivation of a sense of social responsibility. (3) In terms of training methods, there is an emphasis on collaborative training between universities and enterprises, the implementation of a dual-supervisor system, and encouragement for industry mentors to participate in the entire process of doctoral student training. (4) Concerning graduation requirements, there is an emphasis on the practical value of the final submissions by doctoral students.

However, compared to traditional doctoral education, the cultivation of engineering doctoral professional talents in China still exhibits strong path dependence. For example, training objectives are essentially modifications based on those of engineering doctoral education, lacking in-depth understanding and extensive discussion of their connotations. Furthermore, the lack of differentiation between teachers who train engineering doctoral students and those who train engineering doctoral candidates results in converging talents. In terms of curriculum design, it is almost identical to the curriculum for engineering doctoral programs, lacking interdisciplinary elements. Regarding graduation requirements, there is also the use of multiple quantitative indicators as evaluation criteria, such as the number of published papers and the quantity of inventions, which does not significantly differ from the graduation requirements for engineering doctoral students. Currently, universities only establish final graduation requirements, lacking a certain supervision and evaluation system throughout the entire training process. This to some extent affects the quality of engineering doctoral education and is not conducive to cultivating and selecting the most suitable talents for the country's major scientific research projects.

5. Discussion

In over a decade of engineering doctoral education implementation in China, a well-established system for training engineering doctoral candidates has gradually emerged. However, practical challenges persist, necessitating enhancements. These include issues such as the bias in engineering doctoral degree perception, inflexibility in recruitment methods, imposing high entry thresholds and overlooking the broad spectrum of potential candidates, thereby impacting the selection of top-tier talents. Furthermore, there is room for improvement in the interdisciplinary nature of the curriculum, the diversification of quality assurance subjects, deficiencies in the oversight of process quality, and the lack of distinctive characteristics in the training methods (Guo P, Ning X 2020). Drawing insights from the experiences of developed countries in this realm, future improvements in engineering doctoral education should focus on the following aspects.

Enhance the admission standards and widen the student demographic. In alignment with the training objectives for Doctor of Engineering, this program should embody a form of elite education catering to the highest quality of talents, prioritizing excellence over quantity. Consequently, the Doctor of Engineering program should meticulously select high-caliber students based on rigorous standards, upholding a preference-based approach. The admission examination and application requirements serve as the pivotal gateway for talent cultivation and constitute the foundation of training quality. Nevertheless, in China, the criteria merely delineate the relevant engineering fields without specifying distinct professional domains. Moreover, there are numerous constraints on the academic level and background of applicants, impeding the identification of elite talents across diverse fields.

Consequently, the establishment of enrollment requirements for engineering doctoral programs in China should encompass both depth and breadth. Stringent standards for applicants' academic qualifications and work experience are essential to select elite talents. Additionally, defining the applicants' disciplines while relaxing the length of work experience allows for the identification and training of more suitable talents from a broader spectrum.

Strengthen the quality control and introduce the elimination mechanism. The issue of Supervision and evaluation of a work-based PhD is key to influencing the design of such degrees and the output of candidates (Johnson, 2005). In the UK, the evaluation of engineering doctoral students consists of two stages: the mid-term assessment, which includes a written assessment and a review of the opening report after the completion of school courses. Failure to pass may result in removal or downgrading to an educational level, such as transfer to an engineering or engineering master's program with a downgraded registration status. Similarly, in the United States, engineering doctoral students undergo assessments at various stages, including qualification examinations, preliminary tests, and the final dissertation defense at institutions like the University of Michigan. The qualification exam mandates that students accumulate a minimum of 18 credits before participation, and the preliminary test follows a successful qualification exam to assess their comprehension of the major and auxiliary areas, as well as the depth of understanding in the major research areas. The final dissertation requirements focus on engineering practice and are fulfilled under the guidance of the Dissertation Committee. The composition of the dissertation review committee is diverse, consisting of members with high academic proficiency, including internal professors, researchers, full-time professionals with extensive practical experience, and other university professors. This diverse assembly of evaluators contributes to enhancing the objectivity and scientific rigor of the thesis evaluation process (University of Michigan 2021).

In light of the experiences in Britain and America, there is a need for China to enhance the monitoring system for the quality of engineering doctoral training. This involves establishing and refining a comprehensive quality supervision system encompassing graduate enrollment assessments, mid-term process evaluations, and final results assessments. Furthermore, it is crucial to form a diverse engineering doctoral assessment committee, led by campus experts and comprising members from domestic and international higher education insititutions, enterprises, and research and development units. Drawing upon the distinctive features and strengths of the engineering doctoral degree, an assessment standard guided by applied logic has been devised. During the enrollment assessment phase, emphasis is placed on evaluating candidates' communication skills, proficiency in engineering technology or engineering management, and their potential for further development. This involves analyzing their fundamental technical proficiency and overall project management capabilities. The mid-term assessment for engineering doctoral candidates encompasses their academic progress, opening report, advancements in research topics, and overall performance throughout the study period. Additionally, a mid-term assessment phase incorporates an elimination mechanism. As an illustration, Xi'an Jiaotong University specifies that individuals who do not meet the mid-term assessment criteria can reapply for another mid-term assessment within one year. Failure to pass in subsequent attempts may result in the completion of the doctoral course being affected.

Undoubtedly, the implementation of the "negative list" system necessitates robust policy support. In cases where part-time students with a bachelor's degree are eliminated, they should be granted the option to rejoin their original employment units. Furthermore, they can receive a certificate of completion or an engineering master's degree certificate in related fields, along with a partial refund of tuition fees. This measure aims to alleviate the psychological pressure faced by students who have invested significant time without substantial progress. Currently, the recruitment of full-time engineering doctoral students is gaining traction, making it a new prevailing trend. Consequently, for full-time master's degree students progressing to the doctoral stage, the issuance of a corresponding first-level engineer qualification certificate could be considered. The validity of such a certificate must align with the talent requirements of enterprises, indicating that the corporate sector must also acknowledge the certificate's value. To uphold the impartiality of the assessment process, universities should provide accessible channels for appeals, thereby safeguarding the rights and interests of engineering doctoral students. The establishment of a robust mechanism for assessment, supervision, and evaluation is not only imperative for the development of engineering doctoral programs but also serves as a crucial assurance for enhancing the overall training quality of engineering doctoral students.

6. Concluding Remarks

Training engineering doctoral students is not only a pivotal avenue for graduate education to proactively contribute to the development of an innovative nation but also a strategic focal point for the reform and advancement of degree and graduate education. The establishment of the professional degree of engineering doctor in China is still in its nascent phase, and the training of engineering doctoral students has been progressing with gradual exploration. Overall, the pilot universities have established talent training objectives aligned with national major engineering projects, aiming to cultivate high-level applied elite talents for the development of national engineering science and technology initiatives. They rigorously select engineering doctoral candidates, and the programs are designed to enhance the professional knowledge base of engineering doctors and foster skills in engineering management, leadership, and the resolution of intricate engineering issues. Employing a collaborative university-enterprise training approach, individualized training programs are crafted, with a strong emphasis on a graduation thesis that demonstrates significant practical application, serving as a fundamental requirement for degree conferment.

China has established a relatively comprehensive system for engineering doctoral student training, and the meticulous planning at each stage underscores the distinctive features of engineering doctoral education compared to that of other doctoral programs. However, at times, the emphasis on distinctions overlooks the fundamental principles of the talent training process. To enhance the quality of engineering doctoral education in the future, it is imperative to broaden the pool of students and extend the range of selection. In contrast to the research-oriented and inquiry-based learning model prevalent in engineering Ph.D. programs, postgraduate programs for experienced engineers must prioritize different aspects (Dunlap, et al.2003).

In the training of engineering doctoral students, the emphasis should be on fostering innovation-based learning within the framework of applied logic. Concurrently, it is essential to establish and enhance the supervision and evaluation mechanisms in engineering doctoral education. Universities should continually refine the school-enterprise collaborative education structure, delineate a comprehensive school-enterprise responsibility framework, clarify the roles and obligations of both educational institutions and enterprises in scientific research projects, and address issues such as benefit distribution. As the demand for professional engineering doctors is anticipated to rise in the future, the effective training of high-quality engineering doctors within universities should emerge as a focal point for future educational research.

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