A practical ability training system for graduate students majoring in civil and hydraulic engineering based on professional competence characteristics

Fang Liu[1,*], Jian Wu[1], Shaojun Fu[1,2], Yuqian Wang[1], Xinxiao Chen[1], Gang Li[1]

[1]School of Civil Engineering, Xijing University, Xi'an, 710123, China
[2]School of Civil Engineering, Wuhan University, Wuhan, 430072, China

*Corresponding author: liufang_winter@163.com

Abstract. Professional degrees focus on practice, emphasizing vocational skills and application. In recent years, enrollment in these programs has steadily increased, making it a mainstream trend in graduate education. However, a common issue with professional degree programs is the lack of clear differentiation from academic graduate education, leading to limited effectiveness in professional practice. In the present work, we conducted a comprehensive analysis of the current challenges in professional degree education. Additionally, we explored an industry-oriented, progressive, and multi-dimensional ability training goal for graduate students majoring in engineering. We also developed a quality evaluation index system for the practice sessions of civil and hydraulic engineering professional degree programs. Leveraging the full-time master's program in civil and hydraulic engineering at Xijing University as a case study, we aim to investigate a new model of practical teaching in these professional graduate programs.

Keywords: Professional competence; civil and hydraulic engineering; professional degree; practical skills; training system

1 Introduction

China's professional master's degree education began in 1991. Since then, it has expanded its range of professional degree programs and increased the scale of training, achieving significant achievements over the past 30 years and contributing a substantial number of skilled professionals to the country's economic development [1, 2]. To better align with social development and address the urgent demand for high-level applied talents in the country's economic growth, China is actively advancing professional master's degree education tailored to its unique context.

According to the *Developmental Plan for Professional Graduate Degree Programs (2020–2025)* issued by the Academic Degrees Committee of the State Council and the Ministry of Education, the enrollment of professional master's degree students is expected to increase to approximately two thirds of the total master's degree enroll-

J. Yin et al. (eds.), *Proceedings of the 4th International Conference on New Media Development and Modernized Education (NMDME 2024)*, Advances in Intelligent Systems Research 188,
https://doi.org/10.2991/978-94-6463-600-0_15

ment by 2025. This initiative underscores a proactive response to the country's major development strategies, industry transformation and upgrading, as well as the current and future demand for talent. It adheres to a problem-oriented approach and emphasizes the goal of training high-level applied professionals [3]. To enhance the teaching quality of full-time master's professional degree education, the Ministry of Education has issued *Opinions on the Training of Full-time Master's Professional Degree Graduate Students.* This document outlines guiding principles and requirements that emphasize a "comprehensive, coordinated, and sustainable" development approach. The aim is to promote coordinated development, provide classified guidance, standardize management, and ensure the quality of training for professional master's degree graduate students [4].

As a province with a strong focus on education, Shaanxi Province has also formulated relevant policies to improve the training system for professional master's degree students. The Education Department of the Shaanxi Provincial Government has initiated pilot programs for the comprehensive reform of professional master's degree education. The goal is to create a graduate education system with unique Shaanxi characteristics that aligns with regional needs in terms of scale and structure. This system will feature distinctive training models, continuously improve overall quality, and cultivate exceptional innovative talents, thereby providing robust support for the region's economic and social development [5]. To improve the classification training mode for professional master's degree students and enhance their practical innovation capabilities, the Education Department of the Shaanxi Provincial Government and the Shaanxi Provincial Development and Reform Commission jointly issued the *14th Five-Year Plan for the Development of Education in Shaanxi Province* [6].

Regarding the training process for professional master's degree students, the *Opinions on the Training of Full-time Master's Professional Degree Graduate Students* issued by the Ministry of Education emphasize the goal of cultivating high-level applied specialists. This requires students to master solid foundational theories and extensive professional knowledge in their specific field. They should also develop strong problem-solving abilities, be capable of performing professional technical or management tasks, and uphold high standards of professional ethics [4, 7]. The *Overall Developmental Plan for Master's and Doctoral Professional Graduate Degree Programs* highlights that professional degrees follow a relatively independent educational model, characterized by a specific vocational focus and a high degree of integration between vocational and academic aspects [8]. The vocational aspect is primarily ensured through mentor guidance, curriculum design, and professional practice, while the academic aspect is achieved through adhering to academic standards [9, 10].

Professional master's degree education requires a combination of academic, practical, and career-oriented elements, with a focus on economic and social development as well as industry advancements. Practical teaching is crucial in the training of professional master's students. However, a common challenge in professional degree education is the insufficient differentiation from academic graduate programs, which often leads to minimal practical impact and a disconnect between professional and academic orientations. Therefore, enhancing the effectiveness of practical education for professional master's students is an urgent priority [11, 12].

Using the full-time master's program in civil and hydraulic engineering at Xijing University as a case study, we proposed a new practical teaching model for graduate education in this field. This model is grounded in disciplinary knowledge, aligned with the needs of industrial development, and emphasizes the development of engineering practical skills. The aim is to identify a scientific, rational, and feasible approach to improving the quality of training high-level applied talents.

2 Main Issues

Since the inception of full-time professional master's degree education, various educational institutions have continuously explored and refined practical teaching models tailored to their specific contexts, yielding significant results. However, due to various influencing factors and constraints, several challenges in practical teaching within professional degree education remain unresolved and require urgent research and solutions.

(1) The training standards for professional master's and academic master's degrees lack clear differentiation. Consequently, engineering practical skills are insufficient and disconnected from industry needs. Additionally, the competency goals often fall short of aligning with engineering practice, and effective practical teaching models still require further exploration.

(2) The issue of isolated, fragmented, and scattered practical teaching is prominent, with weak integration between practical teaching and other educational activities. This lack of cohesion results in low teaching effectiveness and hinders the achievement of learning goals.

(3) Current practical teaching suffers from inaccurate industry positioning, with significant uncertainty and variability in the establishment of university-enterprise joint practice bases, which are often scattered. Furthermore, the joint training mechanism requires improvement and effective implementation.

(4) The practical teaching system, which should focus on the forefront of industrial development, is not well-established, and a comprehensive dynamic improvement mechanism has yet to be developed.

In China's modernization efforts, civil and hydraulic engineering has emerged as a pillar industry for national economic development. As society and technology advance, construction projects are becoming larger in scale, and increasingly complex and diverse in both function and technology. The use of new materials, structures, equipment, theories, and construction techniques in these projects is evolving rapidly. Construction projects are evolving into composite platforms that integrate multiple disciplines and technologies. This includes the combination of fields such as artificial intelligence, control science, material science, and life science, along with the incorporation of energy-saving technology, information control technology, and ecological technology. Consequently, the industry's demand for civil and hydraulic engineering professionals with higher knowledge levels and better practical capabilities is growing increasingly strong. Therefore, it is essential to address the challenges of practical training for professional master's degrees, align with the core requirements of engineering master's programs, and enhance the training quality of graduate students in civil and hydraulic engineering.

3 Goals and Evaluation Index System for Engineering Practice Abilities

In the current industrial landscape, the training of Master of Engineering students is encountering new requirements, challenges, and opportunities. Xijing University carries out training work based on the principles of being industry-driven, outcome-based education, addressing key challenges, and fostering innovative solutions, as illustrated in Figure 1. It has established a practical ability training system based on the characteristics of professional abilities.

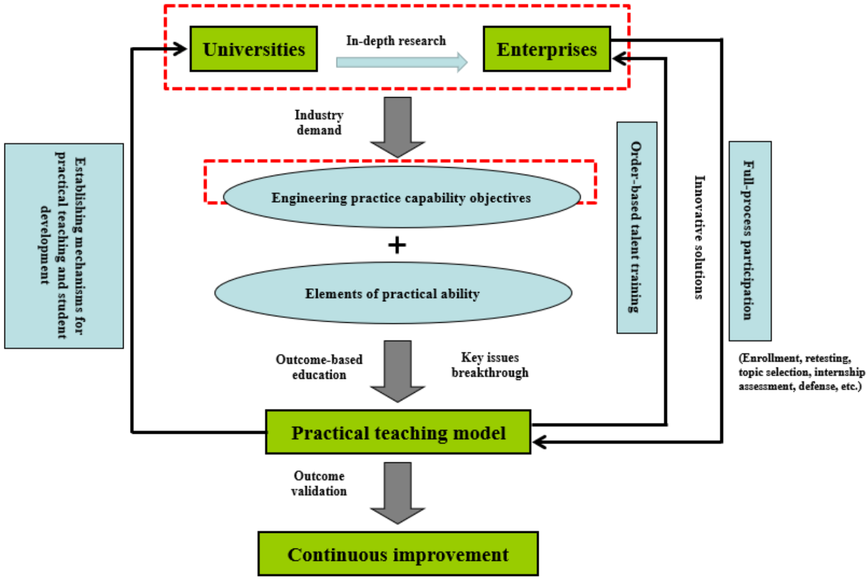

Fig. 1. The practical teaching model for professional degree programs

3.1 Training Goals for Engineering Practice Competencies

The overarching goal of professional master's degree education is to cultivate high-level engineering technology and management talents who possess a strong theoretical foundation, broad professional knowledge, and a blend of craftsmanship spirit and artistic literacy. These individuals are prepared to meet the demands of the economic frontlines, national infrastructure development, and industry growth. Consequently, students in professional master's programs in civil and hydraulic engineering should possess the ability to identify problems through engineering and critical thinking. They should be able to analyze issues using foundational theories and professional knowledge from various disciplines, including mathematics, mechanics, management, structural principles, design, construction, operation, and maintenance. Additionally, they need to solve engineering challenges using professional tools such as software, instruments, and modern technologies, as well as effectively communicate and articulate these engineering problems.

From the perspective of the training process, the quality of graduate education encompasses the quality of input resources, the training process itself, and the resulting outcomes [13]. Therefore, the quality evaluation index system for the practical session of professional master's degree students in civil and hydraulic engineering should be industry-oriented and should progressively and multidimensionally define the students' training goals. Based on the actual training situation of professional master's degree students in civil and hydraulic engineering, we propose four main training goals: knowledge acquisition, knowledge transformation, practical innovation, and professional competence. Each of these goals includes three sub-objectives, as illustrated in Figure 2.

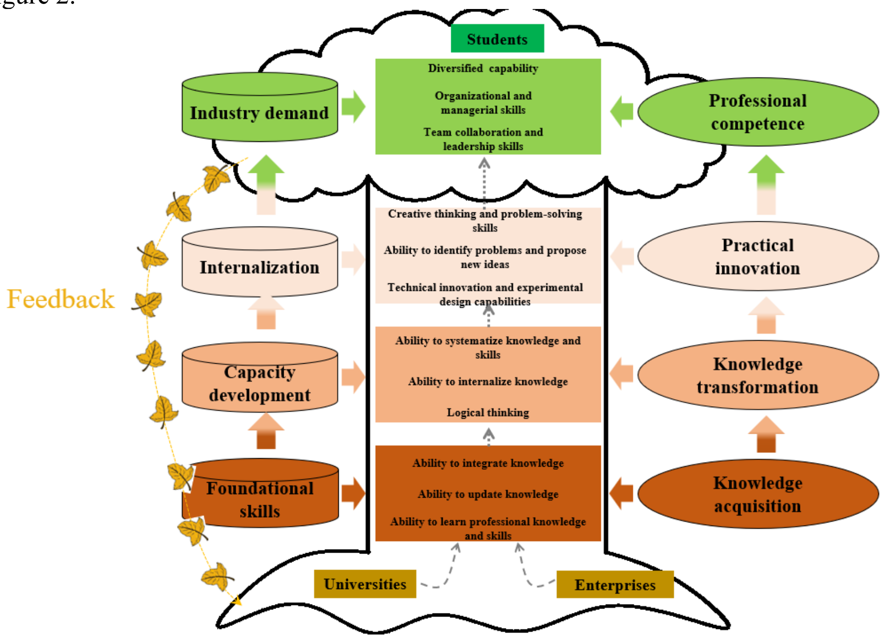

Fig. 2. Progressive training goals for engineering practice competencies

(1) Ability to Acquire Knowledge → Solidifying Foundational Skills

1) Ability to Learn Professional Knowledge and Skills

Guided by the discipline requirement of civil and hydraulic engineering, students should actively learn classic theoretical knowledge using effective learning methods and strategies, and apply various skills to verify theoretical knowledge based on understanding.

2) Ability to Update Knowledge

Students should have a comprehensive understanding of the development trends and frontiers of civil and hydraulic engineering, as well as advancements in modern science, technology, and software. They should stay current with contemporary trends, maintain cognitive acuity and critical thinking, and selectively incorporate new knowledge to replace outdated concepts during their learning process. Additionally, they should be able to adapt to the evolving needs of society, the economy, and the industry.

3) Ability to Integrate Knowledge

Through literature reviews, participation in academic conferences, and active engagement in discussions, students can gain a comprehensive understanding of both discipline-specific and interdisciplinary knowledge. This process enables them to develop a tailored knowledge portfolio that meets the needs of civil engineering and aligns with current advancements in engineering science and technology.

(2) Ability to Transform Knowledge → Capability Development

1) Logical Thinking Skills

Students should be able to think critically and rationally. Leveraging scientific logical methods, they are required to accurately and systematically articulate their thinking processes through observation, comparison, analysis, synthesis, abstraction, generalization, judgment, and reasoning of experimental phenomena and engineering activities.

2) Internalization of Knowledge

Students can enhance their ability to analyze problems by applying their theoretical knowledge. This enables them to employ relevant knowledge and skills to analyze and explore issues that arise in materials, structural tests, and actual engineering cases.

3) Ability to Systematize Knowledge and Skills

Students should have a comprehensive understanding of both professional knowledge and skills. They should grasp the relationship between these two areas and develop a tailored ability-knowledge (skill) system that is suited for engineering practice.

(3) Practical Innovation Capability → Internalization Capability

1) Technological Innovation and Experimental Design Ability

By leveraging their acquired knowledge and skills, students can engage in independent thinking, design and implement scientific experiments, research practical problems, and foster innovation. This process helps to unlock their creative potential and stimulate their imagination.

2) Ability to Identify Problems and Propose New Ideas

We should cultivate in students a spirit of willingness and courage to practice, empowering them to identify problems during their learning and practice. This includes looking beyond surface issues to grasp the essence of the problem and applying their existing knowledge and skills to evaluate and propose innovative solutions.

3) Creative Thinking and Problem-solving Skills

Students can propose innovative solutions by dialectically applying existing experiences and traditional methods and validate their proposals through the final results.

(4) Occupational Competencies → Industry Needs

1) Team Collaboration and Leadership Skills

Students should be equipped with the abilities and qualities to influence and guide others. By leveraging their information, knowledge, and skills, they can achieve common goals through effective teamwork.

2) Organizational and Managerial Skills

Students should be able to reasonably arrange and allocate resources, set clear goals and plans, and address challenges through effective communication and coordination. They should foster a positive work environment and team culture while motivating team members to achieve both individual and collective goals.

3) Diversified Capability

Students are able to adapt to various fields, cultures, and roles. They can respond flexibly to changes and continue to grow and improve in multiple areas by leveraging their knowledge, proficient skills, and diverse experiences.

3.2 Progressive Capability Chain' Practice Capability Evaluation Index System

When constructing the quality evaluation index system for the practical session, it is essential to analyze its fundamental characteristics while fully considering the impact of human and process factors. In the vertical dimension, we should monitor and manage the cultivation process at each stage of practical activities, placing particular emphasis on key activities. In the horizontal dimension, efficient allocation of resources—such as personnel, equipment, and funds—is crucial, forming a three-level management system that includes the university, school, and team. Considering the discipline characteristics of civil and hydraulic engineering, it is essential to strengthen the link between professional degrees and vocational qualifications. This system serves as a crucial reference for evaluating the practical ability development of full-time professional master's degree students.

The practical session is a comprehensive grey system characterized by multiple interacting factors and a broad range of indicators. Selecting appropriate evaluation indicators is essential for achieving an accurate and scientific quality assessment. Based on the actual situation of practical training for graduate students majoring in civil and hydraulic engineering at Xijing University, and combined with literature research and the Delphi method, a quality evaluation index system for practical teaching in civil and hydraulic engineering graduate programs is proposed. This system includes five aspects (primary indicators): course practical teaching arrangement (X_1), dual mentor collaboration (X_2), operation of practical training bases (X_3), graduation outcome assessment (X_4), and assessment feedback mechanism (X_5). Subsequently, the primary indicators are further classified into secondary indicators. The progressive practical teaching model is shown in Figure 3, and the specific hierarchical structure is presented in Table 1.

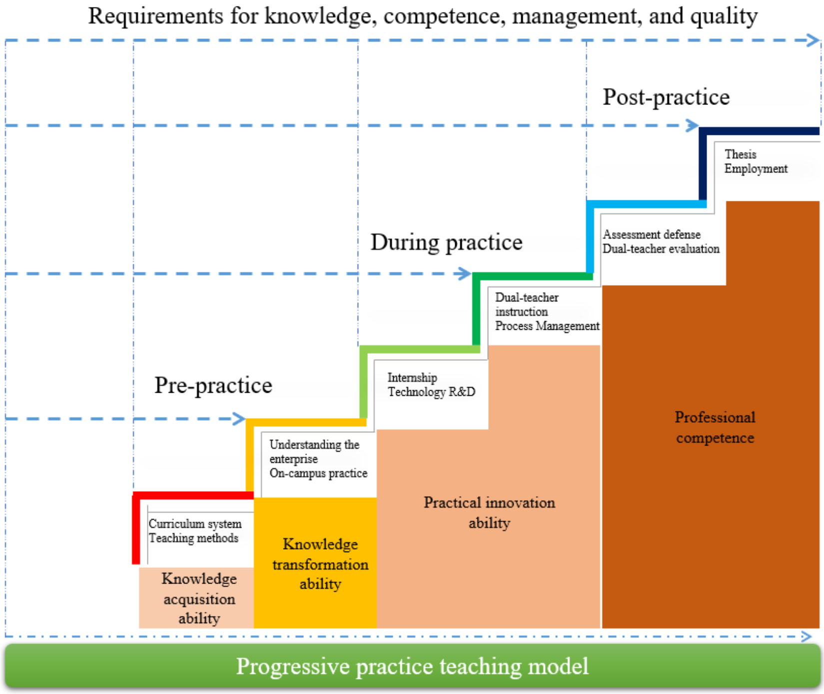

Fig. 3. Progressive practice teaching model

Table 1. Evaluation index system of practical ability for graduate students in civil and hydraulic engineering

Primary indicators	Secondary indicators	Evaluation criteria
On-campus practical teaching X_1	Rational curriculum system X_{11}	The relevance of teaching content to professional characteristics and requirements of professional qualification certificate examinations.
	Diverse teaching methods X_{12}	Case-based teaching, experimental teaching, project-based innovative training;
	Course practical session X_{13}	The proportion of practical learning hours to total learning hours.
Dual Mentorship X_2	On-campus mentor research capability X_{21}	Professional title, research project level, whether the research project funding meets the training requirements, and publication status of papers.
	External supervisor's guidance ability X_{22}	Engineering background, job title, years of work experience, and relevance of major.
	Attitude of external supervisor X_{23}	Frequency of communication with

		students (times/week).
	Division of responsibilities for on-campus mentors and external supervisors X_{24}	Whether management regulations for on-campus mentors and external supervisors are established. Whether a performance evaluation system for both on-campus mentors and external supervisors is established.
	The number of students guided by on-campus mentors and external supervisors X_{25}	Number of students/number of external supervisors.
Off-campus internship base X_3	Internship base basic conditions X_{31}	Whether there are professional testing equipment and personnel to meet the requirements of practical teaching. Whether there are sufficient internship positions available for students.
	Base construction funds X_{32}	Whether there is funding support for the construction of off-campus practice bases.
	Internship working content X_{33}	Whether the workload is full. Whether students have solved engineering-oriented scientific problems.
	Research results transformation X_{34}	Whether the internship experience benefits teaching and research.
	Internship position X_{35}	Relevance to the field of study.
Graduation outcome assessment X_4	Internship report X_{41}	Depth of the internship report Whether the internship defense process is standardized.
	The “four-one” goal X_{42}	Whether there is a close relationship between patents, professional qualifications, journal papers, and participation in projects and engineering issues.
	Thesis X_{43}	Whether the thesis topic is closely relevant to the engineering practice. Percentage of consistency between the thesis and professional practice of graduates in the past three years.
Appraisal and feedback mechanism X_5	Comprehensive assessment of the training process X_{51}	Whether the supervision of the theoretical and practical teaching process is standardized. Whether the interim inspection of the results of the practice is standardized.
	University-Enterprise Communication X_{52}	Frequency of university-enterprise communication (times/year).

3.3 Evaluation Methods and Analysis

(1) Grey Clustering Evaluation

The quality of the practical session is divided into three grey clusters (s=3), namely A-level, AA-level, and AAA-level, corresponding to the evaluation levels of "general", "good", and "excellent" respectively. The evaluation criteria are established based on the *Notice on Forwarding the Guiding Training Program for Full-time Master's Degree Graduate Students (Degree Office [2009] No. 23)* issued by the Ministry of Education [14], as well as the Delphi method, which is commonly employed when consulting evaluation experts.

(2) Whitenization Weight Function

Grey clustering is a method of clustering observational indicators into different categories using whitenization weight functions. In the present work, we employ the triangular whitenization weight function, with the calculation formula as follows:

$$f_j^k(x) = \begin{cases} 0, & x \notin [a_{k-1}, a_{k+2}] \\ \dfrac{x - a_{k-1}}{\lambda_k - a_{k-1}}, & x \in [a_{k-1}, \lambda_k] \\ \dfrac{a_{k+2} - x}{a_{k+2} - \lambda_k}, & x \in [\lambda_k, a_{k+2}] \end{cases} \tag{1}$$

where $f_j^k(x)$ is the whitenization weight function for Grey Cluster k of the Indicator j, calculating the membership degree of Indicator j to the Grey Cluster k; Indicator j is the j-th indicator among the 18 indices in the quality evaluation system of the practical session; k represents the grey cluster, namely the level of the practical stage; a_k is the grey cluster boundary value obtained through the Delphi method; $\lambda_k = (a_k + a_{k+1}) / 2$.

(3) Calculation of the Clustering Coefficient and Clustering Vector for Whitenization Weight

The comprehensive clustering coefficient σ_i^k of objects $i(i = 1, 2, \cdots, n)$ with respect to gray cluster $k(k = 1, 2, \cdots, s)$ is calculated by the formula:

$$\sigma_i^k = \sum_{j=1}^{m} f_j^k(x_{ij}) \cdot \eta_j \tag{2}$$

where $f_j^k(x_{ij})$ denotes the membership degree of Indicator j with respect to Grey Cluster k; η_j represents the weight of Indicator j in the comprehensive clustering.

(4) Evaluation analysis

This project selects the quality of practical teaching for graduate students majoring in civil and hydraulic engineering at Xijing University as a case study for empirical analysis. Based on the constructed indicator system, the evaluation results are obtained after data processing and input into the model. The quality of the practical training for graduate students majoring in civil and hydraulic engineering at Xijing University is in the gray category of AA level, which means the quality level is good. It belongs to AAA level in terms of dual mentor collaboration; It belongs to AA level in practical teaching arrangement, graduation outcome assessment, and appraisal and feedback mechanism; It belongs to A level in the operation of practice bases. The operation of practice bases is a key focus for universities, especially in terms of the scale of the practice base, management funds, and off campus internship positions, which should be strengthened.

4 Conclusion

With the industry's ongoing development and upgrading, there are new requirements for the practical abilities of professional master's degree students in civil and hydraulic engineering. This study thoroughly analyzes the current challenges in professional degree education and explores a new model for practical teaching within the training process for these students. It aims to define engineering master's training goals in an industry-oriented, progressive, and multi-dimensional manner, while also constructing a quality evaluation index system for the practical sessions of professional master's degree students in civil and hydraulic engineering. After a decade of implementation, this approach has yielded a series of successful experiences and notable results. In recent years, full-time faculty members in the civil and hydraulic engineering graduate program at Xijing University have successfully secured a provincial education teaching reform project, established a provincial teaching case base, and developed a provincial civics demonstration course along with a corresponding teaching team. Moreover, graduate students have won one provincial first prize, 11 provincial second prizes, and 24 provincial third prizes in China Graduate Electronics Design Contest; one national second prize and four national third prizes in China Undergraduate Mathematical Contest in Modeling; one national third prize in Energy Equipment Innovative Design Competition for China Postgraduate; Four provincial bronze prizes in "Internet Plus" Competition; one provincial third prize in "Challenge Cup" Shaanxi Extracurricular Academic and Technological Works Competition for College Students; one bronze prize in "Creating Youth" Shaanxi College Students' Entrepreneurship Competition; one national first prize, one national second prize, and one national third prize in National English Competition for College Students (Class A); 14 excellent master's theses; 206 papers published in international and domestic journals; six authorized invention patents, 267 authorized utility model patents, and a total of 180 certificates of various industry qualifications. Feedback from employers regarding the quality of student training has been positive. Graduates from Xijing University have emerged as an indispensable and significant force in engineering construction in the western region of China.

Acknowledgment

This work was supported by the Research and Practice Project of Comprehensive Reform of Graduate Education in Shaanxi Province"Research and Practice on the Practice Model of Professional Degree Graduate Students Based on Subjects and Guided by Industries" (YJSZG2023130) and the Research Project on Graduate Education and Teaching Reform of Xijing University"Research and Practice on the Practice Model of Professional Degree Graduate Students Based on Subjects and Guided by Industries" (2022-YJG-01).

References

1. China National Plan for Medium- and Long-Term Education Reform and Development (2010-2020) [EB/OL]. (2010-07-29) [2023-07-20]. https://wenku.baidu.com/view/cc4146d57-6a20029bd642dc2.html?fr=sogou&_wkts_=1668415060357.
2. Opinions on Deepening the Reform of Graduate Education by the Ministry of Education, the National Development and Reform Commission, and the Ministry of Finance [EB/OL]. (2013-04-19) [2023-07-20]. http://www.moe.gov.cn/srcsite/A22/s7065/201304/t20130419_154118.html##1.
3. Developmental Plan for Professional Graduate Degree Programs (2020–2025) by the Academic Degrees Committee of the State Council and the Ministry of Education [EB/OL]. (2020-09-25) [2023-07-20]. http://www.moe.gov.cn/srcsite/A22/moe_826/202009/t20200930_492590.html.
4. Opinions on the Training of Full-time Master's Professional Degree Graduate Students issued by the Ministry of Education [EB/OL]. (2009-03-19) [2023-07-20]. http://www.moe.gov.cn/src-site/A22/moe_826/200903/t20090319_82629.html.
5. Notice from the Education Department of Shaanxi Province on Carrying out Pilot Comprehensive Reform of Academic and Professional Graduate Education [EB/OL]. (2014-11-17) [2023-07-20]. http://jyt.shaanxi.gov.cn/news/jiaoyutingwenjian/201411/17/8564.html.
6. The 14th Five-Year Plan of Shaanxi Province Education Development [EB/OL]. (2022-04-22) [2023-07-20]. http://jyt.shaanxi.gov.cn/news/jiaoyutingwenjian/202204/22/20420.html.
7. Bie D. R, Zhao Y. C., Yan J. Z. Interpretation of Professional Degree Concept and Its Positioning [J]. Journal of Higher Education, 2009, 30(06). 52-59.
8. China State Council Academic Degrees Committee. Notice on Issuing the "Overall Plan for the Development of Master's and Doctoral Professional Graduate Education" and the "Methods for Setting up and Authorizing Master's and Doctoral Professional Degrees" (Degree [2010] No. 49) [Z]. 2010
9. Du Y. Q, Li G. H., Wang D. M. Problems and Countermeasures in the Practical Teaching of Full-time Professional Master's Degree Students: An Empirical Analysis Based on Expert Interviews [J]. Journal of Graduate Education, 2017, 38(2): 69-74.
10. Xiang X. H, Li Q. H, Liu J. A Qualitative Study on the Practical Ability Structure of Full-time Professional Master's Degree Postgraduates [J]. Academic Degree and Graduate Education, 2016, 37(3): 62-68

11. Chen M. F. The Unity of Professionalism and Academicism: The Necessity of Full-time Master's Professional Degree Graduate Education [J]. Journal of Architectural Education in Institutions of Higher Learning, 2017, 26(3): 9-12.
12. Ji C. Y. Analysis and Reflection on the Current Situation of Professional Degree Education in China [J]. Reform Opening, 2015(24):104-105.
13. Jiang E. L. Total Quality Management: A New Paradigm for Quality Management in Engineering Master's Education [J]. Academic Degree and Graduate Education, 2007(3): 12-16.
14. Notice on Forwarding the Guidance Plan for the Professional Degree Postgraduate Education of Master of Laws [EB/OL]. (2017-07-20) [2023-07-20]. http://www.moe.gov.cn/s78/A22/A22_zcwj/201708/t20170821_311503.html.