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REVIEW

The elements and reform path of core competencies for excellent engineers in China

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ABSTRACT

In the context of the continuous evolution of the new industrial revolution, cultivating a large number of excellent engineers is an effective path to empower China's high-level scientific and technological self-reliance and promote the development of new productive forces. As a key evaluation indicator for measuring the quality of excellent engineer training, core competencies have significant academic value and practical significance when studied systematically. Based on existing research literature, this paper systematically discusses the elements, measurement, and pathways of core competencies for excellent engineers. The research results show that: (1) In terms of concept and theoretical foundation, there is currently no unified definition of core competencies for excellent engineers, and analyses are mainly based on the theory of competence-based education and the iceberg model. (2) In terms of constituent elements, there are two typical models: the Anglo-American system, which emphasizes comprehensive qualities, and the Franco-German system, which emphasizes practical abilities. The current design of core competency standards for excellent engineers in China mainly focuses on learning from the Anglo-American system, relatively neglecting the cultivation of practical abilities. (3) In terms of research methods, qualitative research methods are predominantly used, while quantitative methods are less applied. (4) In terms of influencing factors, the core competencies of excellent engineers are influenced by a mix of multiple stakeholder groups, including learners, educators, universities, governments, enterprises, and society. (5) In terms of policies to promote reform, current research mainly argues from five levels: institutional, organizational, pedagogical, technological, and evaluative.

Key words: excellent engineer, core competencies, certification standards, engineering education

INTRODUCTION

Under the accelerating global technological revolution and industrial transformation, the Report to the 20th National Congress of the Communist Party of China explicitly coordinates the strategic deployment of education, science and technology, and talent development for building a strong education system. In this context, outstanding engineers emerge as pivotal elements and core forces that drive technological innovation waves, propel transformative industrial upgrading, and safeguard national security. As the paramount national priority in self-reliant cultivation of high-end talent, cultivating outstanding engineers is constitute the strategic entry point, critical leverage, and ultimate litmus test for constructing an education powerhouse. In recent years, research on the cultivation of engineers of excellence has emerged as a prominent topic in the fields of education and engineering. Scholars and experts from diverse perspectives have engaged in extensive discussions and analyses, yielding valuable insights (Li *et al.*, 2010). However, in contrast to the theoretical discourse, the reality of China's engineering education system reveals a concerning trend of scienti-

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fication and a significant mismatch between the demand for practical skills and the supply of qualified professionals. The fundamental issue lies in the inadequate comprehension of the cultivation orientation of exemplary engineers. Consequently, it is imperative to meticulously categorize and profoundly examine the research findings on the composition and constituents of the core qualities of superior engineers, the influencing factors, and the reform pathways observed in other countries. (Chu, 2016) This will facilitate a more precise identification of the attributes and qualities that should be cultivated in engineers, thereby providing valuable insights and guidance for China's engineering education to nurture a greater number of highly skilled engineering and technical professionals with global competitiveness.

CONCEPTS AND THEORETICAL RESEARCH

In 2002, the European Union's "Key Competences for the Knowledge Society" report initially delineated core competencies as a compilation of transferable, multifunctional, and indispensable knowledge, skills, and attitudes that facilitate personal growth, social integration, and work competence (DESECO, 2024). Since then, academia has provided new interpretations of the concept of core competencies from different perspectives, with two representative perspectives: the functional perspective and the professional perspective. In 1997, the Organization for Economic Cooperation and Development (OECD) launched the project "Definition and Selection of Literacy: Theoretical and Conceptual Foundations" (DeSeCo Project), defined core competencies from a functional operational standpoint, emphasized those involved in multiple life domains and contributing to personal success and social well-being. German scholar Mertens, on the other hand, explains core competencies from the perspective of professional adaptability, referring to knowledge, abilities, and skills not directly related to specific professional skills but rather the capacity to make judgments and choices in various situations and responsibilities, and the ability to compete with unforeseen changes in life. However, a consensus can be reached that core competencies are abstract contents beyond specific skills, consisting of knowledge, skills, and attitudes, emphasizing problem-solving abilities and personal growth.

The concept of core competencies for excellent engineers, or the characteristics that distinguish excellent engineers, remains a topic of debate within academic circles. The specific abilities required for excellence in engineering vary considerably depending on the engineering discipline in question. Nevertheless, they are united by the necessity of possessing fundamental qualities and essential characteristics, centered on the capacity to solve intricate engineering problems in an information-based, intelligent, and diversified environment. In practical evaluation research, many scholars often adopt a perspective that is oriented towards graduate requirements, certification standards, or general standards when studying excellent engineers (Liu, 2018). This approach can result in an overlap or mutual inclusiveness with core competencies. The precise interrelationships between these factors remain the subject of ongoing research, and a unified research approach and definition have yet to emerge.

In developing a core competency system for excellent engineers, scholars primarily draw upon competency-based education theory and the Iceberg Model as theoretical support and analytical perspectives (Zhang, 2021). Firstly, competency-based education theory, which originated from the training of American skilled workers during World War II, posits that educational content and methods should be closely aligned with students' actual needs and competency levels. The core principle of this theory is to systematically analyze and define the competency components that are necessary for engaging in specific occupations based on the actual job demands of those occupations. Once these components have been identified, training objectives are set and a comprehensive teaching model is constructed, which includes teaching content, methods, processes, and effect evaluations. This theory has had a profound impact on the evolution and development of the global vocational education system, and has been widely applied in China's higher vocational education practice since its introduction in the 1990s. In the pursuit of excellence in engineering education, numerous scholars employ competency-based education theory as a foundational principle in the construction of core competency indicators, advocating for a more scientific and rational selection of indicators and the establishment of a more robust.

Secondly, the Iceberg Model, which was innovatively proposed by David McClelland based on the concept of "competency," aims to comprehensively depict the internal structure of individual qualities. The model identifies two dimensions of individual competencies: explicit competencies, which are above the surface, and implicit competencies, which are below it. Explicit competencies are primarily constituted of skills and knowledge that are readily discernible, quantifiable, and cultivable. In contrast, implicit competencies encompass values, self-cognition, personality traits, and intrinsic motivation, which are often challenging to directly observe. Additionally, they exhibit a number of characteristics, including environmental relevance and behavioral orientation. In the field of research on the core competencies of excellent engineers, the Iceberg Model provides a valuable theoretical framework that guides researchers to conduct in-depth analysis and gain a comprehensive understanding of the complex composition of engineers' competencies. This provides a more profound and comprehensive perspective for the cultivation and evaluation of excellent engineers.

CONSTITUENT ELEMENTS RESEARCH

Research and discussion on the core competencies of excellent engineers have been conducted relatively earlier in Western countries, and a relatively mature framework system of elements has been formed. Among them, the frameworks of core competencies for excellent engineers that have attracted extensive attention and research from Chinese scholars mainly focus on the European Union (EU), the United States of America (US), and the United Kingdom of Great Britain and Northern Ireland (UK).

At the international level, there are the Washington Accord published by the International Engineering Alliance (IEA); (International Engineering, 2024) the EUR-ACE® Framework Standards and Guidelines (EASFG) proposed by the European Accreditation of Engineering Education (EANEE); the Professional Competence Requirements for Engineers developed by European Federation of National Engineering Associations (FEANI, 2024) At the national level, there are the accreditation standards proposed by the Accreditation Board for Engineering and Technology of the United States of America (ABET, 2020); the UK Standard for Professional Engineering Competence (UK-SPEC) formulated by the Engineering Council (ENGC, 2024); the Common Standards developed by the German Accreditation Agency for Study Programs in Engineering, Informatics, Natural Sciences and Mathematics (ASIIN, 2024) and the standards designated by the Commission des titres d'ingénieur (CTI) in France (CTI, 2024). As shown in Figure 1.

In China, as engineering education began relatively late, for a considerable period of time, the official certification or ability standards for the core qualities of excellent engineers remained absent. It was not until June 2010 that the Ministry of Education of China initiated the “Excellent engineer Education and Training Program” and formulated the general standards for it. For the undergraduate level, it encompasses three major dimensions- quality, knowledge, and ability- along with 11 element indicators. For the master's level, the abilities of thinking, harmonious and natural innovative development were added, totaling 13 elements. In March 2015, to further enhance the international influence of engineers, the China Engineering Education Accreditation Association (CEEAA), drawing on the “Engineering Criteria 2000” (EC2000) formulated by the ABET of the United States, released new general standards, and officially joined the Washington Accord in June 2016. The two aforementioned standards for engineering talents, which have been officially issued and exert a significant influence, have a profound impact on the cultivation of engineering talents in China, as detailed in Table 1. Furthermore, a considerable number of scholars in China have used different perspectives or theories to divide the abilities required for excellent engineers into different fields, in order to construct their own core competency system for engineering talents, as illustrated in Table 2. It is noteworthy that a small subset of scholars have focused their research on specific components of the core competencies of excellent engineers. These include the cultivation of engineering practical abilities (Zhang, 2014), innovative capabilities (Song, 2011) and leadership skills (Lin, 2012). This has led to a further refinement of the research angles of the core competencies for excellent engineers.

A comparative analysis of engineering talent standards across various foreign nations reveals numerous similarities and underlying principles that are shared across the board. These standards universally acknowledge the pivotal role of engineering talent in propelling scientific and technological advancements, economic growth, and societal progress. Furthermore, there is a consensus on the fundamental attributes required for engineering professionals, which is reflected in the universal prioritization of students' knowledge bases, abilities, and communication skills. However, due to the disparate social systems, historical backgrounds, and cultural traditions of different countries, there are some notable discrepancies in their respective tendencies and emphases. As a result, these discrepancies also manifest in the tendencies of their engineering personnel training standards. These standards can be broadly categorized into two archetypal models, according to their distinctive characteristics and emphases. The first is the Anglo-American system, which emphasizes comprehensive quality and holistic development. The second is the French-German system, which emphasizes practical ability and technical proficiency.

China's engineering talent training curriculum system was initially modeled on the engineering education paradigm of the Soviet Union. In this context, students tend to prioritize the acquisition of theoretical knowledge over practical engineering experience. In the wake of the 1990s, China's engineering education sector underwent a profound transformation, with a notable shift towards the engineering education model prevalent in the United States and other developed countries. This shift involved enhancing the connection between general and professional education, strengthening the integration

Table 1: Official general standards for core competencies of domestic engineering talents

Name	Primary indicators	Specific connotation or second indicators
General standards for excellent engineer training program (Master's Degree; Lin, 2010)	Quality	Basic quality
		Modern engineering awareness
	Knowledge	Basic knowledge
		Professional knowledge
		Technical standards and policies and regulations
	Ability	Learning ability
		Thinking ability
		Analyzing and problem-solving ability
		Creative consciousness and development and design ability
		Creative development and harmony with nature
		Management and communication skills
		Crisis management ability
		International exchange and cooperation
Graduate competency standards of China engineering education professional certification association (general standards for engineering education accreditation, 2022)	Engineering knowledge	Ability to apply mathematics, natural sciences, engineering fundamentals, and professional knowledge to solve complex engineering problems
	Problem analysis	Ability to apply the basic principles of mathematics, natural sciences, and engineering sciences to identify, express, and analyze complex engineering problems through literature research, in order to obtain effective conclusions.
	Design/development of solutions	Ability to design solutions to complex engineering problems and to demonstrate a sense of innovation in the design process, while taking into account social, health, safety, legal, cultural, and environmental factors is crucial
	Research	Ability to conduct research on complex engineering problems based on scientific principles and using the scientific method
	Use of modern tools	Ability to develop, select and use appropriate techniques, resources, modern engineering tools and information technology tools for complex engineering problems and to understand their limitations
	Engineering and society	Ability to conduct reasonable analysis based on engineering related background knowledge, evaluate the impact of professional engineering practice and complex engineering problem solutions on society, health, safety, law, and culture.
	Environment and sustainability	Ability to understand and evaluate the impact of engineering practices on the environment and sustainable development of society for complex engineering problems.
	Professional norms	Having humanities and social science literacy, a sense of social responsibility, understand and abide by engineering professional ethics and norms in engineering practice, fulfilling responsibilities.
	Individuals and teams	Ability to assume the roles of individual, team member, and leader in a team in a multidisciplinary context.
	Communication	Ability to communicate and interact effectively with industry peers and the general public on complex engineering issues, and articulating or responding to instructions with some international perspective
	Project management	Understand and master the principles of engineering management and economic decision-making methods and apply them in a multidisciplinary environment
	Lifelong learning	Having the awareness of self-learning and lifelong learning, and the ability to continuously learn and adapt to development

of the basic curriculum with the professional curriculum, and prioritizing the comprehensive literacy of engineers.

For this reason, a comprehensive assessment of the aforementioned analyses reveals a crucial insight: irrespective of whether one considers official standards or the core competency frameworks developed by various scholars within China, the emphasis on the evaluation of practical abilities represents a relatively minor component. This can be confirmed from the sorting of the above table. This phenomenon largely explains the prevalent tendency in China's engineering talent training to prioritize theoretical knowledge over practical application. This imbalance is evident in several key areas. With regard to the orientation of the educational system, the positioning of engineering colleges in China appears to lack clarity, with an insufficient emphasis on an “engineering-oriented” approach. Conversely, there is a perceptible transition towards a “science-oriented” paradigm in engineering

Table 2: Personal standards for core competencies of domestic engineering talents

Originator	Primary indicators	Secondary indicators
Wu Tao, Liu Nan, Sun Kai (Wu *et al.*, 2018)	Professional spirit	Patriotism
		Ecological awareness
		Professional ethics
	Professional ability	Engineering thinking ability
		Engineering practice ability
		Innovation and entrepreneurship ability
	Sustainable development capability	Lifelong learning ability
		Cross-border integration ability
		Leadership ability
Wang Shibin, Gu Yuzhu, Qi Haixia (Wang *et al.*, 2020)	Engineering capability	Systems thinking
		Decision making
		Leadership collaboration
		Lifelong learning
	Specialized ability	Creative thinking
		Analyzing cognition
		Explore and discover
		Standardized execution
	General ability	Humanistic thinking
		Questioning and criticizing
		Logical reasoning
		Communication
	Key character traits	Moral thinking
		Ideals and beliefs
		Family and national sentiments
		Ethical responsibility
Zhang Wei, Wang Liang, Qian Heyi (Zhang *et al.*, 2020)	Disciplinary literacy	Disciplinary cognitive ability
		Knowledge reflection ability
	System literacy	Metacognitive ability
		Interdisciplinary competence
		System design capability
	Computational literacy	Computational thinking
		Abstract ability
	Information literacy	Information processing capability
		Self-iteration ability
		Situational ability
	Ethical literacy	Professional ethics
		Social responsibility
Zheng Lina, Jiang Zijiao, Lei Qing (Zheng *et al.*, 2022)	Basis behavioral ability	Non-cognitive personality traits
		Interpersonal and social abilities
	Domain specific capabilities	Humanistic literacy
		Scientific foundation
		Engineering ability
		Systematic thinking
	General competence in the field	Global competence
		Innovative thinking
		Cutting-edge insight
		Situational adaptability
		Cross-border integration ability
	Excellent behavioral ability	Social responsibility and ethics
		Self-regulation and development
		Sustained creativity

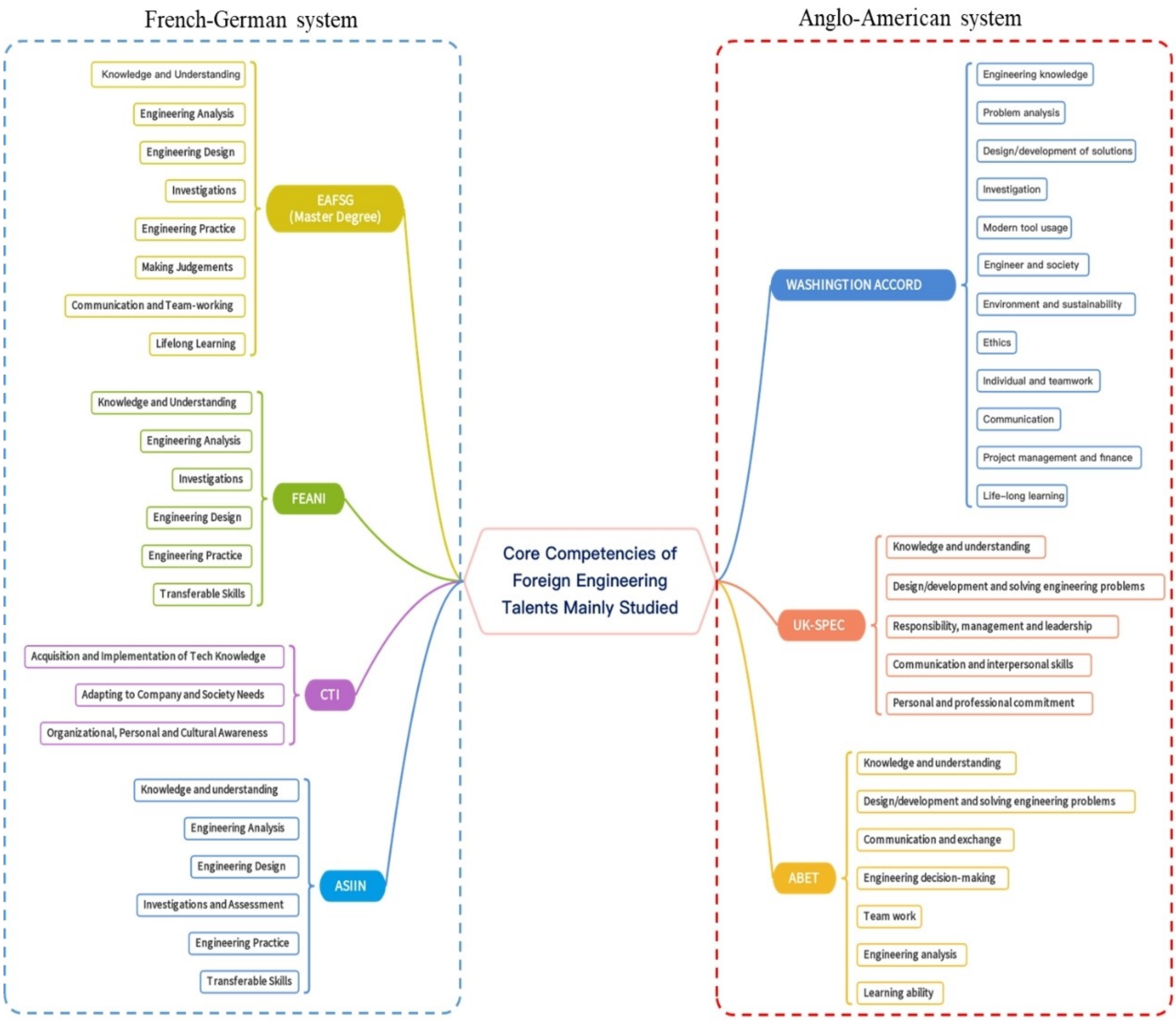

Figure 1. General standards for core competencies of foreign engineering talents mainly studied.

education. This shift not only dilutes the focus on practical skills and hands-on experience but also risks aligning engineering curricula more closely with theoretical pursuits in the sciences, thereby potentially undermining the practical competencies required by the engineering profession. Moreover, with regard to assessment and evaluation methodologies, the extant system is largely contingent upon written examinations as the principal instrument for ascertaining students' preparedness for graduation. While these examinations may effectively gauge theoretical understanding, they are inadequate for assessing experimental and practical skills and abilities, which are equally vital for engineering professionals. The consequence of this is an emphasis on learning for examinations rather than the application of knowledge, which has resulted in a notable deficiency in practical training within the educational process. This deficiency in training not only impairs students' capacity to integrate effectively into the workforce but also exacerbates the discrepancy between the cultivation of engineering talent and the actual requirements of enterprises. As a result, this discrepancy presents a significant societal challenge, as it undermines the efficacy of engineering education in addressing the demands of a rapidly evolving technological landscape, and has also caused a serious disconnect between the training of engineering talents and the actual needs of enterprises and other social problems.

MAIN RESEARCH METHODS

In terms of method selection, existing studies have predominantly employed qualitative research methods, including the case study method, text analysis method, rooted theory method, and interview method. While quantitative methods have been less frequently utilized, the questionnaire method represents the primary quantitative approach, frequently employed in conjunction with the interview method. One of the most frequently utilized qualitative research methods is the case study method. This method allows for the in-depth exploration of a specific phenomenon, issue, or theory by examining a particular case in great detail. This approach enables researchers to gain insights into the intricacies, evolving dynamics, and internal workings of the case under investigation. In response to the global issue of cultivating excellent engineers, some scholars introduce four domestic universities that have been effective in the sustainable development of engineering talents, including Arizona State University and East China University of Science and Technology. From the three dimensions of educational vision, specific actions, and supporting conditions, extracted from the practical experience of the engineering education of these universities, the key competencies for promoting the sustainable development of engineering talents were identified. Subsequently, a future-adapted engineering talent core literacy framework was constructed (Gao, 2022).

The second principal method of applied research is text analysis, which is a systematic examination of text structure, variable relationships, and factual results through the quantitative processing of text content to elucidate intrinsic information, insights, and patterns. This method is frequently employed in conjunction with comparative analysis. In the construction of the core literacy system for engineers of excellence, scholars frequently draw on the advanced experience of Western countries. Some scholars have indicated that the construction of key competency models for new engineering talents should be based on scientific, operational, and forward-thinking principles (Guo, 2023). This can be achieved through a textual comparison of the Washington Accord, the Conceive-Design-Implement-Operate (CDIO) Syllabus Version 2.0 (2011) and the competency standards for engineering talents, as exemplified by the Olin Institute of Technology (Hu & Li, 2021).

The third principal method is the interview method, which allows for a more detailed capture of respondents' viewpoints and event details, is a widely employed technique in the construction of the core literacy system, the exploration of the root causes of the problems, and the development of improvement strategies. Some scholars conducted three rounds of correspondence with experts to assess the reasonableness of the structural model of the constructed value system. This process yielded the value system of core literacy for new engineering talents, which is composed of five dimensions and 20 literacy indicators (Zhang *et al.*, 2022).

The fourth principal method is rooted theory method, which is a qualitative research approach that constructs theories from empirical data. It focuses on direct theory creation from data by seeking core concepts reflecting reality, based on systematic data collection. Relevant social theories are then formulated through concept interconnections. Some scholars conducted a comprehensive analysis of summary reports from 40 "Excellence Plan" pilot universities, employing a three-level coding system. A comprehensive examination of 320 concepts, 24 categories, and six primary themes (organizational and management, quality assurance, policy and management, internal and external policy-guaranteed incentives, school-enterprise cooperation, talent training, and teacher development) revealed the emergence of two distinctive relational structures, which serve to reinforce the interconnectivity between educational institutions and their surrounding business communities (Lu *et al.,* 2018).

The questionnaire method is the most frequently utilized quantitative research technique for examining the fundamental literacy competencies of exemplary engineers. As a standardized data collection method, it is frequently utilized for the gathering of core literacy elements and the examination of the present state of cultivation (Liu & Zhang, 2023).

INFLUENCING FACTORS RESEARCH

A review of existing studies reveals that scholars frequently employ the analytical paradigm of system theory when examining the factors influencing the core literacy of excellent engineers. In accordance with the tenets of system theory, any system is regarded as an organic entity with a specific function, constituted by a multitude of elements interconnected in a defined structural configuration. In the system of cultivating engineers with excellence, the aforementioned elements-including learners, educators, universities, governments, enterprises, and society-function as the core elements of the system (Liu, 2018). These elements interact and influence each other, collectively promoting the evolution and development of the system. Based on the viewpoint of system theory and the existing literature, the two major influencing factors of internal subject and external environment can be analyzed.

The inner subject encompasses both the learner and the educator. In the process of cultivating engineers with excellence, learners, as the primary subjects of learning, must fully utilize their own subjective initiative. However, due to the inherent differences among learners, their subjective initiative may manifest in either a positive or negative manner. This intrinsic factor significantly influences the cultivation of engineers with excellence. Wang Chao, Li Bingbing, and other scholars posit that students' attitudes play a significant role in influencing the cultivation of core literacy, particularly in terms of practical abilities (Wang *et al.,* 2022). The impact of educators' engineering expertise on the cultivation of essential literacy skills among engineers of excellence has also garnered significant interest from numerous scholars. Despite the existence of a regulation pertaining to engineering experience among teachers in the context of the "Excellence Program", (Lin, 2013) a number of colleges and universities have not yet established a dedicated "engineering" teaching position. This is due to a range of factors. There is a notable discrepancy between the theoretical knowledge imparted by these engineering educators in the classroom and the practical operational requirements of enterprises. This makes it challenging for them to effectively fulfil their role in guiding students through engineering practice tasks.

In examining the factors that shape the external environment, scholars have identified four key domains for analysis: universities, government, enterprises, and society. From the perspective of system theory, scholars posit that the two major internal subjects, namely, the learner and the educator, exert a direct influence on the quality of engineering education. With regard to the external macro-environment, it is imperative that the policy support system be promptly enhanced, the implementation of university mobility be reinforced, and the capacity of enterprises to engage in the process be fortified. The transformation of social and cultural values exerts an indirect influence on the quality of engineering education, which in turn constitutes a significant macro-factor affecting the institutional construction of engineering education.

As a policy guide, the government promotes the cultivation of excellent engineers by issuing a series of policies. For example, guiding the establishment of national engineering colleges or excellent engineering innovation research institutes. These research institutes have formed a technology industry talent training and innovation special zone led by the government, operated by entities, and oriented towards industry needs. Despite many policies promoting the integration of industry and education, scholars believe that the government lacks effective cooperation mechanisms and legal frameworks to regulate and promote comprehensive cooperation between industrial enterprises and higher education institutions in engineer training (Jiang, 2016). This policy flaw poses a challenge to deepening cooperation and stabilizing partnerships between these entities.

Universities serve as the primary trainers of excellent engineers. Prior research has shown that academic institutional support directly impacts the cultivation of core competencies among these engineers. However, scholars largely conclude that the pedagogical approach in engineering education at colleges and universities needs improvement (Wang, 2020). There is a notable lack of clear positioning in the cultivation objectives of engineering institutions, with the inertia towards cultivating scientific research talents remaining dominant. This is accompanied by an excessive emphasis on theoretical knowledge and a relative neglect of practical abilities. Regarding teaching evaluation, colleges and universities rely on singular indices, and their evaluation methods are not adequately aligned with cultivation objectives. The criteria are overly simplistic and inflexible, undermining the positive function of academic evaluation in fostering the core qualities of excellent engineers.

Enterprises, as practical service providers for cultivating excellent engineers, not only facilitate school-enterprise cooperation but also grapple with conflicts of interest and conceptual biases that hinder their growth. There exists an imbalance in the attitudes of schools and enterprises towards such cooperation, with schools demonstrating enthusiasm while enterprises display indifference. This disparity stems from a lack of incentives, concerns regarding production order and safety, and inadequate compensation for enterprise interests. Additionally, discrepancies in interest recognition and differences in educational and production legislation pose significant challenges in aligning cooperation objectives. Often, enterprises perceive school-enterprise cooperation solely as a recruitment channel, overlooking its intrinsic educational value. Some scholars argue that enterprises' primary motivation for engaging in such cooperation is their demand for talent and technology; if this demand is unmet, enterprises will lack sufficient interest and investment (Yi *et al.,* 2015).

Society, as a cultural shaper, is intricately linked with values. However, from an international lens, it is apparent that our country lags in fostering engineering excellence within social thought. There is a notable dearth of emphasis on engineering talent, especially the worth of excellence in this field, leading to a gradual decline in the profession's appeal and a pervasive perception of low prestige. Notably, some traditional engineering institutions have experienced a significant reduction in volunteer numbers, falling beneath admissions levels, indicating a worrying trend of students shying away from engineering careers and opting for alternatives. Furthermore, over 60% of respondents reported that engineers in China generally possess low professional social status. This underscores that societal opinion, policy incentives, and educational resource allocation have yet to coalesce into a potent force propelling engineering education towards advanced levels and broader development.

REFORM PATH RESEARCH

In response to the issues that have emerged, scholars have initiated a more comprehensive discourse on the reform pathways and enhancement countermeasures to elevate the caliber of engineering education at various levels. These levels are primarily classified into five categories: institutional, organizational, educational, technological, and evaluative.

From an institutional perspective, the overarching structure of the state plays a pivotal role in fostering the development of human capital in higher education institutions and advancing the transformation and innovation of engineering education. From the perspective of higher education, the policy provides guidance to colleges and universities, encouraging them to clarify the objectives of engineering talent cultivation and adjust their educational orientation in accordance with the needs of national and social development. This entails the establishment of a layered and categorized engineering talent cultivation system, whereby the distinctive advantages of each institution are fully leveraged. Some scholars posit that the current legal system in China is not as robust as that of other countries with respect to school-enterprise cooperation. They argue that the lack of incentives for enterprises to engage in substantive policies, such as funding, project, tax, or loan support, has resulted in a low level of enthusiasm for school-enterprise cooperation in a formal manner. This, in turn, has an adverse effect on the effectiveness of the "Excellence Program". Consequently, it is imperative that the state introduces more targeted legislation and incentives to regulate the conduct of enterprises and stimulate their participation in the cultivation of talent. This will ensure the advancement of school-enterprise cooperation and guarantee the seamless implementation of the "Excellence Plan".

From an organizational perspective, it is evident that the promotion of school-enterprise cooperation at the organizational level cannot be achieved by a single subject. The establishment of a robust organizational structure serves as a crucial assurance for the successful integration of industry and education, as well as for the advancement of school-enterprise cooperation. Some scholars have proposed that the state should establish a platform for the integration of industry and education. In addition, they have recommended that enterprises and colleges and universities should set up internal institutions or departments dedicated to school-enterprise cooperation (Lin, 2023). These would be responsible for planning, organizing, implementing, and evaluating the cooperation projects. Subsequently, a standardized, long-term, and stable school-enterprise cooperation mechanism should be established. A joint steering committee for the "Excellence Program" should be established between the school and the enterprise. This committee should be the core organization of school-enterprise cooperation and be responsible for planning and implementing internship work, as well as maintaining and deepening the relationship between the school and the enterprise. Additionally, scholars have indicated that the establishment of technology research and development and cooperative innovation platforms, with a particular focus on major scientific research projects, could facilitate more profound collaboration between the two parties in the realm of scientific research. This could entail assuming joint responsibility for the risks associated with scientific research, sharing the outcomes of scientific research, and further advancing the transformation of scientific research outcomes (Zhang, 2019). Such an approach could serve as a robust foundation for nurturing "engineers of excellence".

From an educational perspective, colleges and universities should implement a program for the cultivation of engineering talents that is based on scientific and reasonable principles. Some scholars posit that colleges and universities should adhere to a demand-oriented approach, aligning their disciplinary and specialization structures with the evolving industry and market demand for diverse talent types. This entails optimizing the curriculum to prioritize core competencies, with a particular focus on strengthening practical skills and expanding internship opportunities (Zhi & Han, 2015). It is also essential to ensure that the teaching content is updated in a timely manner to guarantee that the knowledge conveyed is current and relevant. Furthermore, the establishment of interdisciplinary courses is crucial to facilitate the breakdown of knowledge and organizational barriers, enabling effective responses to the challenges posed by increasing complexity. Additionally, numerous scholars have advocated for the enhancement of engineering education faculty. This entails the recruitment of qualified individuals from abroad and the internationalization of the teaching staff (Liu *et al.*, 2024). Furthermore, the acceleration of the training and development of "dual-teacher" professionals is essential. The evaluation of engineering education faculty should be based on their ability to solve practical engineering problems, the industrial benefits they generate, and the effectiveness and scale of graduate student training. Additionally, a relaxed atmosphere for research and teaching should be fostered, and scientific and rational evaluation, appointment, and incentive mechanisms should be implemented to truly drive the initiative of teachers to engage deeply in scientific research and talent cultivation in engineering education (Fu *et al.*, 2023).

From a technological perspective, in light of the challenges posed by the digital intelligence era, it is imperative to leverage advanced technologies such as GenAI to enhance teaching. AI has the potential to serve as a powerful tool in various aspects such as intelligent learning environment, intelligent classroom instruction, intelligent extracurricular learning, intelligent engineering practice, and intelligent evaluation of education and teaching (Lin & Yang, 2024). Students can engage in the process and promptly obtain professional knowledge, innovative methodologies, and new competencies pertinent to the task at hand. Additionally, they can experience the dynamic updating of the knowledge system. Generative artificial intelligence can also provide students with an immersive practice environment, compensating for the lack of practical teaching and enhancing their capacity to solve novel problems by simulating complex engineering scenarios (Zhou, 2016). And it is imperative to reinforce the cultivation of students' lifelong learning abilities. This encompasses not only the updating of professional knowledge but also the acquisition of new methods and skills. This enables continuous adaptation to the challenges of industrial digitization and intelligence through the engineering learners' conscious efforts. It also facilitates continuous improvement in the ability to solve new problems and self-driven growth in the workplace (Qiao *et al.,* 2023).

From an evaluative perspective, in order to facilitate the advancement and enhancement of engineering professionals' core literacy skills, it is essential to develop a comprehensive, multidimensional, and meticulously scientific evaluation system that assesses their practical engineering abilities. Some scholars posit that the core literacy of engineering talents is a comprehensive concept, comprising knowledge, attitude, and skills. Accordingly, a comprehensive evaluation index system should be established to not only quantitatively and qualitatively describe students' knowledge and skills, but also to assess their ability to integrate these elements. Furthermore, value judgments on students' spiritual qualities should be incorporated. In addition, the existing evaluation standards should be revised to include assessment of students' practical ability in solving engineering problems, as well as their autonomy and self-discipline in following engineering practice norms. The existing evaluation criteria should be revised to prioritize the assessment of students' practical abilities in solving engineering problems and their autonomy and self-discipline in following engineering practice norms (Qu, 2024). Furthermore, some scholars have put forth the idea that the evaluation system should incorporate a dynamic feedback and improvement mechanism to drive the continuous optimization of teaching content and methods based on evaluation results. This would ensure that evaluation results can effectively guide teaching practice and promote the continuous improvement of talent cultivation quality.

DECLARATION

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Ethics approval

Not applicable.

Conflict of interest

The author declares no conflict of interest that could be perceived.

Use of large language models, AI and machine learning tools

AI assistance is utilized in certain literature search and accuracy review of language expression efforts.

Data availability statement

Not applicable.