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Practice-Focused Teaching Strategies in Engineering Education: A Systematic Review of Competency Development and Implementation Contexts

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Abstract

This study uses a systematic literature review method to analyze 30 high-quality literatures to comprehensively explore the application status of practice-oriented teaching strategies in engineering education, the effect of ability training, and the influencing factors of its implementation context. The study found that a variety of practical teaching strategies have been developed in the field of engineering education, including project-based learning, work-integrated learning, and service learning, and these strategies are undergoing a transformation from fragmented application to systematic integration. These teaching strategies aim to cultivate students' technical professional ability, general ability, and comprehensive literacy, but their effectiveness is affected by multiple contextual factors such as institutional environment, resource conditions, teacher roles, and industry participation. The evaluation method also shows a trend of change from single evaluation to multiple, from terminal to formative, and from teacher-led to multi-subject participation. The research results support an integrative, contextualized, and developmental view of engineering education reform, emphasizing the importance of systematic thinking and adaptive implementation, and providing theoretical guidance and practical paths for cultivating engineering talents that meet future needs.

Keywords: Engineering Education, Practice-Oriented Teaching, Ability Development

Introduction

As a key pillar of the higher education system, the quality of engineering education is closely related to the national innovation system and industrial competitiveness. In recent years, the global industrial structure has been restructured at an accelerated pace. Digital transformation and intelligent manufacturing have profoundly changed the connotation and form of engineering practice, and the traditional engineering education model faces severe challenges (Lucas, 2014). In this context, the cultivation of engineering practice ability has become the core proposition of contemporary engineering education reform. Higher education institutions in major industrial countries and regions in the world are actively exploring practice-oriented teaching strategies, aiming to cultivate a new generation of engineering talents with systematic thinking, innovative spirit and practical ability to meet global engineering challenges and sustainable development needs (Graham, 2018).

The core mission of engineering education is to cultivate professional talents who can cope with complex engineering problems and promote technological innovation and social progress. However, traditional engineering education has a significant tendency of "focusing on theory and neglecting practice". The curriculum system and teaching methods overly focus on the inculcation of basic theoretical knowledge, while paying insufficient attention to the cultivation of students' practical ability, critical thinking and innovative spirit (Sheppard et al., 2009). A large number of studies have shown that although engineering graduates generally have a solid theoretical foundation, they often show problems such as lack of practical experience, limited interdisciplinary collaboration ability, and insufficient project management effectiveness when facing complex problems in real engineering scenarios (Male, Bush and Chapman, 2011). This disconnect between theory and practice has attracted widespread attention in the field of engineering education, prompting educational researchers and practitioners to re-examine the goal positioning, curriculum design and teaching methods of engineering education.

As an educational innovation in response to the above challenges, practice-focused teaching strategies have occupied a core position in the global wave of engineering education reform in recent years. This series of teaching methods systematically integrates real engineering problems, industry projects and professional practical experience into the curriculum design and teaching process by organically integrating theoretical learning and practical experience (Kolmos and de Graaff, 2014). In these teaching environments, students not only acquire professional knowledge, but also cultivate problem-solving skills, professional judgment and engineering ethics awareness through active participation, collaborative exploration and reflective practice. Practice-oriented teaching strategies include, but are not limited to, project-based learning, situational teaching, cooperative education, and service learning, which together constitute an important path for the reform of contemporary engineering education (Edström and Kolmos, 2014). Although there are a considerable number of case studies and experience reports on various practice teaching methods, there is still a lack of comprehensive and in-depth analysis of how these strategies systematically promote the development of engineering capabilities, as well as their adaptability mechanisms and implementation effects under different educational backgrounds, cultural environments, and resource conditions.

Trends of Practice-Focused Teaching Strategies

The development of practice-oriented teaching strategies in the field of engineering education shows a clear evolutionary trajectory and diversified trend. From a historical perspective, the development of these strategies has experienced a process of paradigm shift from single teaching experiments to systematic education, reflecting the profound changes in the concept and methodology of engineering education (Feisel and Rosa, 2005).

Since the 1990s, with the international development of the engineering education certification system, the concept of outcome-based education has gradually become the mainstream, promoting the overall rise of practice-oriented teaching (Froyd, Wankat and

Smith, 2012). The implementation of the US ABET engineering certification standard EC2000, the establishment of the European engineering education quality assurance system, and the global expansion of the "Washington Accord" have jointly built an international consensus that emphasizes the cultivation of practical ability (Lattuca et al., 2006). Against this background, practice-oriented teaching strategies in the field of global engineering education show several significant development trends.

Practice-oriented teaching strategies are undergoing a transformation from fragmented application to systematic integration. Early attempts at practical teaching were mostly limited to a single course or experimental link, lacking holistic design and cross-course collaboration (Borrego and Bernhard, 2011). In recent years, more and more engineering schools have begun to build a practical ability development system throughout the entire training process, organically integrating practical elements into course groups and training programs, and forming a spiral ability training path (Crawley et al., 2014). The global promotion and application of the CDIO (Concept-Design-Implement-Operate) engineering education framework is a typical representative of this trend, which emphasizes the construction of an integrated practical teaching system from the perspective of the entire life cycle of engineering products (Edström and Kolmos, 2014). Practice-oriented teaching is gradually expanding from the closed environment on campus to the collaborative innovation ecology of industry, academia and research. Traditional engineering practical teaching mainly relies on on-campus laboratories and simulation projects, which is difficult to truly reflect the complexity and uncertainty of engineering practice (Graham, 2018). The emerging practical teaching model pays more and more attention to establishing in-depth cooperation with the industry, and builds a collaborative education environment of "school-enterprise-society" through the industry co-construction of laboratories, enterprise internship bases, and the introduction of real projects (Heywood, 2016). The deepening of this industry-university cooperation not only provides students with a more realistic engineering experience, but also promotes the dynamic connection between educational institutions and industrial needs (Johri and Olds, 2014).

The rapid development of digital technology is profoundly reshaping the form and connotation of practice-oriented teaching. The application of technologies such as virtual laboratories, augmented reality, and remote experimental platforms has broken the time and space limitations of traditional practical teaching and expanded the depth and breadth of practical experience (Potkonjak et al., 2016). The introduction of digital twin technology enables students to interact with complex engineering systems in a virtual environment and experience the various constraints and trade-offs in the real engineering decision-making process. In addition, the application of big data analysis and learning analysis technology provides new possibilities for accurate evaluation and personalized guidance of the practical teaching process (Marbouti et al., 2016).

Practice-oriented teaching strategies are increasingly incorporating social responsibility and sustainable development dimensions. Contemporary engineering practice faces global challenges such as the environment, energy, and health, requiring engineers to have a broader vision and a deeper sense of social responsibility (Nieusma and Riley, 2010). Teaching strategies such as community-based service learning and project-based learning around the United Nations Sustainable Development Goals organically combine social needs with engineering education, and cultivate students' comprehensive thinking ability and moral judgment in complex social and technical systems (Mitchell et al., 2021). Practice-oriented teaching evaluation methods are developing in a diversified, process-oriented and formative direction. Traditional examination evaluation is difficult to accurately reflect the formation process and level of practical ability (Felder and Brent, 2003). In recent years, performance-based evaluation, electronic portfolio evaluation, peer evaluation and other methods have been widely used in practical teaching evaluation, forming a more comprehensive and realistic ability evaluation system (Turns et al., 2012). These innovative evaluation methods not only focus on the final results, but also attach importance to reflection and growth in the learning process, providing students with more meaningful feedback (Williams, 2013).

These development trends are intertwined and mutually reinforcing, and together constitute the dynamic evolution of practice-oriented teaching strategies in contemporary engineering education. With the continuous changes in the engineering field and the continuous innovation of educational concepts, the application of practice-oriented teaching strategies in engineering education will be further deepened and expanded, providing a more effective educational path for cultivating engineering talents that meet future needs.

Trends of Engineering Education s in Higher Education

As an important part of the higher education system, the development trend of engineering education is closely related to the global higher education reform and social and economic development. Over the past half century, with the transformation of industrial production methods, the acceleration of scientific and technological progress and the deepening of the globalization process, engineering education has undergone a series of profound changes in the field of higher education, showing a multi-dimensional evolutionary feature.

The connotation and boundaries of engineering education are undergoing major adjustments. Traditional engineering education mainly focuses on the imparting of subject knowledge and the solution of technical problems, while contemporary engineering education emphasizes the cultivation of students' ability to cope with complex social and technical systems (Johri and Olds, 2011). This transformation stems from a new understanding of the essence of engineering practice—engineering is not only a process of applying natural science knowledge to solve technical problems, but also a complex activity of creation and decision-making under multiple constraints such as society, economy, environment, and ethics. Engineering degree programs have gradually shifted from a single technology orientation to an integrated training model, focusing more on cultivating students' systematic thinking, innovative design, and interdisciplinary collaboration capabilities (Bucciarelli, 2003).

Innovation in curriculum design and teaching methods has become a core issue in the reform of engineering education. The linear curriculum system based on traditional lecture-based teaching has been widely questioned, and various student-centered teaching methods have been promoted and applied (Prince and Felder, 2006). Innovative teaching strategies such as problem-based learning, project-based learning, and flipped classrooms have been widely practiced in engineering colleges. Curriculum design has gradually broken down disciplinary barriers and built a more integrated teaching system through comprehensive project courses and through-the-line ability training paths. These innovative teaching methods have not only changed the way knowledge is imparted, but also reshaped the teacher-student relationship and the learning process, turning engineering education from one-way indoctrination to multi-dimensional interaction and inquiry collaboration (Smith et al., 2005).

The collaborative relationship between industry and education is becoming increasingly close. Global engineering education is undergoing a transformation from an "ivory tower" to an "open system", and is establishing closer cooperative relations with industry, government, and social organizations (Genheimer and Shehab, 2009). The participation of industry experts in curriculum design and teaching activities, the introduction of corporate problems into classroom teaching, and the construction of school-enterprise joint laboratories and research centers have become important means of connecting engineering education with industrial needs. This industry-university cooperation not only promotes the real-time updating of educational content, but also provides students with more practical opportunities and career development paths (King, 2012).

Internationalization and diversification have become the irreversible development direction of engineering education. The global nature of engineering practice requires engineering education to transcend national and cultural boundaries and cultivate future engineers with global competence (Downey et al., 2006). Engineering schools in various countries enhance students' cross-cultural communication skills and international vision through international student exchanges, multinational cooperation projects, global virtual teams and other forms. At the same time, engineering education increasingly attaches importance to diversity and inclusiveness, and is committed to attracting and cultivating more students from different genders, races and cultural backgrounds to address the long-standing problem of insufficient diversity in the engineering field (Chubin et al., 2005).

Digital transformation is comprehensively reshaping the form and content of engineering education. The in-depth application of information technology has not only changed the way knowledge is transmitted, but also created a new learning environment and education model (Bourne et al., 2005). Online courses, blended learning, virtual laboratories and other innovative forms have enabled engineering education to break through the spatial limitations of traditional classrooms.

Review on Competency Development and Implementation Contexts

The "graduate attributes" framework proposed by the International Engineering Alliance divides engineering competence into three categories: technical competence, personal and professional competence, and interpersonal competence (IEA, 2013). Passow (2012) found through a large-scale survey that problem solving, communication, teamwork, and application of professional knowledge are the most important core competences in engineering practice. In response to emerging technologies and social needs, Lima et al. (2017) emphasized the key role of innovation, sustainable development thinking, and cross-cultural competence in contemporary engineering practice. These studies not only enrich the theoretical concept of engineering competence, but also provide a scientific basis for the determination of competence training goals and curriculum design.

The relationship between practice-oriented teaching strategies and engineering competence training has become a research hotspot. Empirical studies have shown that problem-based learning can effectively cultivate students' critical thinking and autonomous learning abilities (Borrego et al., 2013). Project-based learning has unique advantages in promoting students' design thinking and system thinking (Dym et al., 2005).

The study of the long-term effects and migration mechanisms of competency development has expanded the time dimension. Martin et al. (2005) found through follow-up surveys that practice-oriented teaching has a lasting impact on the career development path and adaptability of graduates. Lattuca et al. (2006)'s large-scale survey research confirmed that engineering education reform not only improved students' technical capabilities, but also enhanced their adaptability to changes and uncertainties. Atman et al. (2010) revealed the trajectory and key turning points of engineering design capability development through longitudinal research, providing a basis for the timing of educational intervention. These research results not only expand the time horizon of capability development research, but also provide a scientific basis for the evaluation of the investment benefits of engineering education.

Although existing research has achieved fruitful results, there are still several limitations and challenges in the research on engineering capability development and implementation contexts. There is no broad consensus on the operational definition of the concept of capability, which makes it difficult to directly compare research results (Male, 2010). There is a relative lack of comparative research on different practical teaching strategies, which makes it difficult to provide clear selection basis for educational practitioners (Prince, 2004). A systematic analysis framework for implementation context factors has not yet been formed, which limits the context transfer and promotion of research results (Henderson et al., 2011). The difficulty and cost of long-term follow-up studies have led to insufficient evidence on the long-term effects of competence development (Jesiek et al., 2011). These research gaps provide important directions for future engineering education research and highlight the need for a systematic literature review.

Research Objectives and Research Questions

This study aims to comprehensively explore the application status, ability training effect and adaptive mechanism of practice-oriented teaching strategies in engineering education in different implementation scenarios through a systematic literature review. This research goal stems from in-depth thinking about the challenges facing current engineering education and its reform needs. With the complexity of the engineering practice environment and the improvement of the requirements for engineering talent training, the limitations of the traditional engineering education model have become increasingly prominent, and the effective application of practice-oriented teaching strategies has become particularly important. However, although practical teaching methods have been widely used in engineering education, there is still a lack of comprehensive understanding of the systematic classification, target ability orientation, situational adaptability and evaluation methods of these strategies.

Based on this, this study established four core research questions to guide the development of a systematic literature review:

RQ 1: What types of practice-oriented teaching strategies are currently used in engineering and technology education, and what are their characteristics?

This research question aims to comprehensively sort out and classify the practice-oriented teaching strategies that have been implemented in the field of engineering education, including but not limited to project-based learning, problem-based learning, service learning, cooperative education, situational teaching, etc. By analyzing the characteristics of these strategies, a classification framework for practical teaching strategies is established, and the core elements, implementation methods and applicable conditions of various strategies are clarified, providing a theoretical basis for strategy selection for educational practitioners.
RQ2: What specific abilities or learning outcomes do these teaching strategies aim to cultivate in students?

This research question focuses on the correspondence between practice-oriented teaching strategies and engineering ability cultivation. By systematically analyzing the ability cultivation goals and their implementation paths reported in the literature, identifying the advantages and specific effects of different teaching strategies in ability cultivation, and exploring how practical teaching promotes the coordinated development of students' professional abilities, general abilities and situational adaptability, it provides guidance for ability-oriented teaching design.
RQ3: What situational and institutional factors affect the implementation and effectiveness of these teaching strategies?

This research question explores the implementation environment and influencing factors of practice-oriented teaching strategies. By analyzing the impact of situational factors such as college characteristics, organizational culture, resource conditions, teacher capabilities, and student characteristics on teaching implementation, the key conditions and potential obstacles for the success of practical teaching are identified, and the adaptive mechanisms of teaching strategies in different implementation situations are understood, providing contextualized implementation suggestions for education managers and policy makers.
RQ 4: How are the learning outcomes of these strategies evaluated and measured in the reviewed studies?

This research question focuses on the evaluation methods and evidence system of practice-oriented teaching effectiveness. By analyzing the evaluation tools, indicator systems, and method strategies used in the literature, evaluating the advantages and limitations of existing evaluation methods, exploring an evaluation framework that can comprehensively and accurately reflect the effectiveness of practical teaching, and providing effective evaluation tools and methods for educational researchers and practitioners.

By answering these four interrelated research questions, this study will construct a comprehensive knowledge map of practice-oriented teaching strategies in engineering education, revealing the complex relationship between different teaching strategies, ability training goals, implementation contexts, and evaluation methods. This systematic understanding will provide theoretical guidance for engineering education practice, promote the effective selection, design, and implementation of practical teaching methods, and ultimately improve the quality of engineering education and cultivate outstanding engineering talents that meet the needs of future society.

Research Significance

This study systematically combed the development status, ability training effect and situational influencing factors of practice-oriented teaching strategies in engineering education, which is of great significance in multiple aspects such as theoretical construction and educational practice.

At the theoretical level, this study fills an important knowledge gap in current engineering education research. Although there are a large number of case studies and experience reports on various practical teaching methods, there is a lack of comprehensive efforts to integrate these scattered research results into a systematic knowledge framework. This study enriched the conceptual system and analytical tools of engineering education theory by establishing a classification system of practical teaching strategies, clarifying the correspondence between different strategies and ability training goals, analyzing the influencing mechanism of situational factors, and constructing a comparative framework of evaluation methods. This theoretical contribution not only deepens the understanding of the process of engineering ability development, but also provides a scientific basis for the theoretical construction of practice-oriented teaching, and promotes the development of engineering education research in a more systematic and integrated direction.

At the level of teaching practice, this study provides engineering educators with a scientific guide for the design and implementation of practice-oriented teaching. By systematically analyzing the characteristics, advantages and applicable conditions of different teaching strategies, educators can make more informed strategic choices based on specific teaching goals and situational requirements. The ability cultivation paths and key influencing factors revealed in this study provide a reference framework for the precision and personalization of teaching design. The comprehensive analysis of evaluation methods provides methodological support for the scientific evaluation of teaching effectiveness. These practical guidance will help improve the teaching quality of engineering education, promote the effective implementation of teaching innovation, and ultimately enhance the ability development and career preparation of engineering students.

At the educational management level, this study provides a strategic perspective on the construction of a practical teaching system for college leaders and educational managers. By analyzing the organizational, resource and cultural factors that affect the implementation of practical teaching, this study reveals the key mechanisms and potential obstacles that support innovation in practical teaching. These findings provide a basis for educational reform decisions at the college level and help build an institutional environment and support system that is more conducive to practical teaching. The analysis of the adaptability of practical teaching under different educational backgrounds in this study also provides a reference for colleges and universities to formulate differentiated development strategies based on their own characteristics, and promotes the contextual adaptability and sustainability of engineering education reform.

Methods

This systematic literature review adopts the PRISMA methodological framework as the guiding principle of research design. The PRISMA framework was chosen because of its authority and soundness in the field of systematic reviews. The framework has been widely verified in practice and provides a rigorous research path, which can maximize the integrity of literature collection and the systematic nature of the analysis process. The advantage of the PRISMA framework lies in its structured research step design, which not only effectively reduces the possibility of missing key literature, but also enhances the traceability of the research process and the credibility of the results through its transparent method reporting requirements.

Following the PRISMA guidelines, the methodological process of this study includes four core links: literature identification, preliminary screening, in-depth evaluation and final inclusion. In the literature identification stage, a systematic search was conducted in multiple professional databases through a carefully designed retrieval strategy; the preliminary screening stage was mainly based on the title and abstract content, and literature that obviously did not meet the scope of the study was excluded; the in-depth evaluation stage was strictly screened by reading the full text according to the preset inclusion and exclusion criteria; the final included literature constituted the analysis object of this study. The entire literature screening and evaluation process is shown in Figure 1. The screening results and reasons of each link were recorded in detail to ensure the replicability of the research process and the objectivity of the results. This methodological framework provides a solid scientific foundation for this study and ensures a systematic, comprehensive, and objective analysis of practice-oriented teaching strategies in engineering education.

Identification

This systematic literature review strictly follows the framework design of the PRISMA guidelines, and focuses on the scientific selection of data sources in the initial literature identification stage. Considering the professionalism and academic rigor of the research topic, this study selected the two core academic databases, Web of Science (WoS) and Scopus, as the main search platforms. These two databases not only include high-quality research results in the field of engineering education, but also provide comprehensive citation analysis functions, which help to fully grasp the development context of the research field.

To ensure the accuracy and comprehensiveness of the search results, a systematic combination of search terms was constructed after multiple rounds of discussion and testing. These search terms cover the core concepts of practice-oriented teaching strategies and engineering education, while taking into account variant forms of different expressions. In view of the characteristics of the two databases, Web of Science and Scopus, the research team designed optimized search strategies respectively, using Boolean logic operators and positional operators to accurately locate relevant literature. The specific search strings and their application methods in each database are detailed in Table 1. This refined search strategy design ensures the systematicity and accuracy of the literature collection process, laying a solid foundation for subsequent screening and analysis.

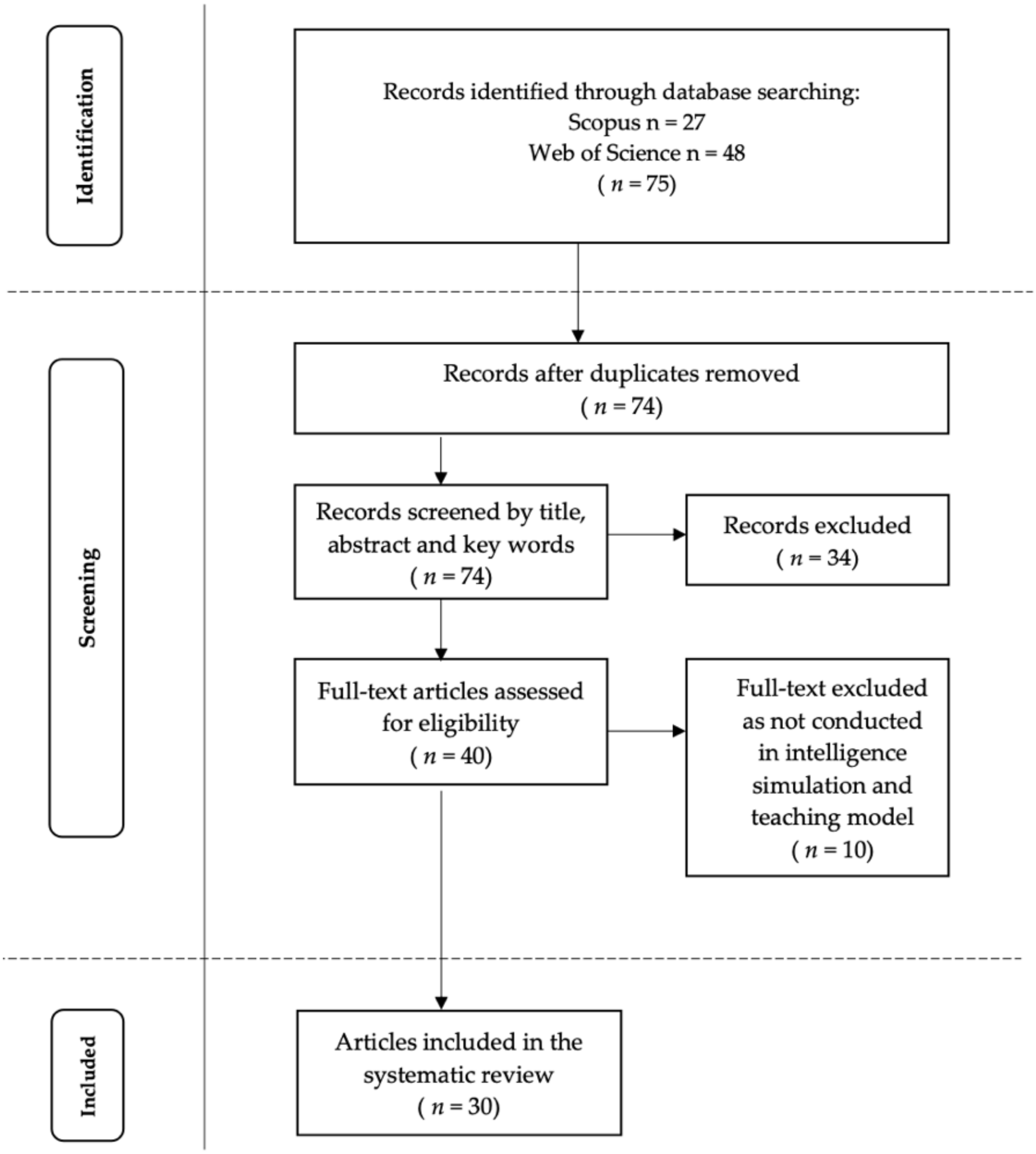

Figure 1 *PRISMA systematic review adapted from.*

Screening and Included

After identifying the articles, a screening process was first performed, and the first step was to remove duplicate articles in multiple databases. After the initial screening, a total of 1 duplicate article was excluded, leaving 74 articles for the next stage of screening. These 74 articles were screened based on title, abstract, and keywords to ensure that they were relevant to intelligent simulation and higher education teaching models. During this process, 34 articles were excluded because they did not meet the purpose of the study. Finally, after further screening of the remaining 40 articles based on the inclusion and exclusion criteria, 30 articles that met the inclusion and exclusion criteria may be included in this systematic review.

Table 1
Search string used in this study

Database	Search String
Scopus	TITLE-ABS-KEY(("competency-based education" OR "outcome-based education" OR "practice-based learning" OR "project-based learning" OR "experiential learning" OR "design-based learning") AND ("curriculum reform" OR "curriculum innovation" OR "engineering curriculum" OR "technical education curriculum") AND ("engineering education" OR "vocational education" OR "technical and vocational education and training" OR "TVET") AND ("skill development" OR "practical skill*" OR "hands-on learning" OR "competency development"))
Web of Science (WoS)	TS=(("competency-based education" OR "outcome-based education" OR "practice-based learning" OR "project-based learning" OR "experiential learning" OR "design-based learning") AND ("curriculum reform" OR "curriculum innovation" OR "engineering curriculum" OR "technical education curriculum") AND ("engineering education" OR "vocational education" OR "technical and vocational education and training" OR "TVET") AND ("skill development" OR "practical skill*" OR "hands-on learning" OR "competency development"))

*: Fuzzy Reference

Data Analysis Procedure
This systematic literature review uses standardized data extraction methods to analyze the included literature. A dedicated data extraction form was designed to ensure that key information is systematically collected from each literature and to maintain the consistency and reliability of the analysis process.

The data extraction form contains the following core elements: Study (basic information of the study, including author, year, paper title and publication journal); Database (database of literature source); Aim (research purpose and focus); Samples (research objects, sample size and characteristics); Findings (main research findings and conclusions).

The literature analysis follows the logical framework of the research question and is carried out from multiple perspectives such as the type of practical teaching strategy, ability training goals, implementation context factors and evaluation methods. The analysis process identifies the commonalities and differences between the literature through multiple readings and comparisons, and summarizes the main findings and knowledge gaps in the research field.

The data integration adopts a narrative synthesis method to systematically organize and compare the evidence and viewpoints scattered in different literatures, and present the current application status of practice-oriented teaching strategies in engineering education.

Results

Teaching Strategies in Practice-Focused Engineering Education

The 30 articles included in the systematic analysis show (see Appendix 1 for details) that a variety of practice-oriented teaching strategies have been developed in the field of engineering education, and these strategies have significant differences in implementation characteristics, teaching objectives, and intervention depth. Through literature analysis, the practice-oriented teaching strategies in current engineering education can be summarized into the following main types.

Project-based learning is the most common practice teaching strategy, and 14 of the included articles focus on or mention this method. Ahmed et al. (2018) introduced project-based learning in the introductory engineering course to cultivate freshmen's engineering skills and problem-solving abilities through multiple project tasks. Luk et al. (2024) adopted a one-week intensive project course in the teaching of biochemical and biomedical engineering to promote students to master technical knowledge and develop interdisciplinary skills. Rehman (2023) significantly improved students' creativity, systematic thinking, and hands-on ability by introducing project-based learning in computer and engineering courses. Tijo-López and Mejía-Aguilar (2024) analyzed the practical effect of project-based teaching in construction engineering management education and found that students had significant improvements in project design and resource scheduling capabilities.

Work-Integrated Learning (WIL) has been identified as an effective strategy for cultivating students' practical ability in many papers. Gambheer and Acharya (2024) explored the improvement of students' engineering practical ability through school-enterprise cooperation, internship mechanism and project-based learning, and found that WIL helps students understand real engineering problems and improve comprehensive skills. Mesuwini et al. (2023) evaluated the impact of WIL on the employment readiness and professional skills development of South African engineering students. The results showed that this strategy enhanced students' problem-solving, time management and professional expression abilities. Service Learning is also an important strategy for developing practical ability in engineering education. Bermúdez et al. (2024) analyzed the influencing mechanism of professional skills and social responsibility development when engineering students participated in service-learning internships, and found that service-learning significantly improved students' professional skills, communication and collaboration skills, and public responsibility awareness. Simpson et al. (2018) studied how the "Digital Ambassador" project promoted the development of soft skills of South African engineering students through extracurricular project work.

Experiential learning has been proven to have a positive impact on engineering capacity development in many literatures. Bill (2022) explored the systematic cultivation of professional skills and problem-solving abilities of engineering students through experiential learning modules throughout the four years of undergraduate studies. Ramírez-Cadena et al. (2024) studied the application of experiential education in technical education and found that students developed more reflective abilities for social practical problems while mastering knowledge, and successfully stimulated enthusiasm for participation and sense of responsibility.

The strategy of combining flipped classroom with practical tasks has also received attention in the literature. Prabhu et al. (2024) explored the impact of flipped classroom combined with project tasks on students' knowledge mastery, hands-on ability and course satisfaction. The results showed that students showed higher initiative and participation in the project-based flipped classroom, and their learning outcomes and practical skills were significantly better than those of the traditional teaching model.

Case-based and simulation learning is used in engineering education to create learning situations close to real engineering environments. Keckstein et al. (2017) designed a mechanical engineering teaching reform experiment based on simulation and practical projects, and found that students' abilities in system modeling and simulation, practical construction, etc. were significantly enhanced. Tarpey (2022) improved students' career readiness and soft skills performance through simulation and case teaching of project management courses. The results showed that the teaching setting helped students achieve significant improvements in communication, organization and coordination, and stress coping.

Technology-Enhanced Practical Teaching has also received increasing attention. Anderson (2019) studied the impact of introducing an automated data acquisition system into a heat pump experiment course on students' initiative and data analysis ability. Salinas-Navarro et al. (2023) studied how teachers integrate emerging technologies to reshape engineering design and manufacturing courses under the background of digital transformation, and confirmed that the integration of digital technology promotes the development of students' practical ability, innovation consciousness and engineering design logic.

In addition, the CDIO (Concept-Design-Implement-Operate) framework has been used by some studies to guide practical teaching design. Ajailia et al. (2024) introduced the teaching design of AI ethics education based on the CDIO framework. The analysis showed that the CDIO framework helps to build an ethical teaching path with projects as the core, and students show higher critical thinking and value judgment ability in the course.

Comprehensive analysis shows that these practice-oriented teaching strategies are different in form, but the core concept is the same, that is, to promote students' transformation from "knowing what" to "being able to do" by closely integrating learning situations with real engineering practices. Most studies in the literature emphasize the importance of systematic design and gradual implementation of practical teaching strategies for the development of students' abilities, and also reflect the trend of mutual integration between different forms of practical teaching.

Targeted Competencies and Intended Learning Outcomes

An analysis of the 30 included literatures found that practice-oriented engineering education aims to cultivate a variety of student abilities and learning outcomes through a variety of teaching strategies. These abilities and learning outcomes can be summarized into three categories: technical professional abilities, general abilities, and comprehensive literacy.

In terms of technical professional abilities, the literature shows that practical teaching strategies focus on cultivating students' practical engineering skills, design abilities, and problem-solving abilities. Ghattas et al. (2024) showed that teaching interventions based on project-driven and agile development significantly improved the project management ability and collaborative experience of software engineering students. Keckstein et al. (2017)'s mechanical engineering teaching reform experiment proved that through modular training projects based on industrial scenarios, students' abilities in system modeling and simulation, practical construction, etc. were significantly enhanced. ElZomor et al. (2018) evaluated the application of project-based teaching in architectural engineering courses and found that students had positive progress in structural understanding and modeling ability. Anderson's (2019) study showed that the introduction of an automated data acquisition system into a heat pump experimental course enhanced students' hands-on ability and data analysis skills.

System thinking and engineering design ability are the core professional abilities that many studies focus on. Dym et al. were cited in Raut's (2024) study, emphasizing the unique advantages of project-based learning in cultivating students' design thinking. Raut et al. (2024) found that multi-stage projects enhanced students' global understanding of the design process and promoted closed-loop feedback between theory and practice. Tijo-López and Mejía-Aguilar (2024) showed that the project-based teaching model can effectively improve students' ability in project design and resource scheduling in construction engineering management education. Salinas-Navarro et al. (2023) confirmed that the integration of digital technology promoted the development of students' engineering design logic.

In terms of general abilities, communication and collaboration skills are the most frequently mentioned learning outcomes. De Matos Alves and Harsh (2018) explored how project-based and experience-based teaching supports engineering students in developing communication skills and found that project-based language training improved students' practical communication skills and self-confidence. Bermúdez et al. (2024) showed that service learning significantly improved students' communication and collaboration skills. Ahmed et al. (2018) showed that project-based learning improved the communication, collaboration and comprehensive expression of first-year engineering students.

Critical thinking and problem-solving skills are also important goals of practical teaching. El Achkar and Alsaba (2024) showed that the introduction of digital humanities and social issues significantly enhanced students' critical reflection ability. Ajailia et al. (2024) found that AI ethics education based on the CDIO framework prompted students to show higher critical thinking and value judgment abilities. Johnson and Ulseth (2017) found that the project-driven learning model enabled students to show stronger integration and solution design capabilities when facing complex problems.

Leadership and project management skills are also important components of general abilities. Simpson et al. (2018) studied the impact of the "Digital Ambassador" project on the soft skills of South African engineering students and found that students gained significant organizational and leadership growth through actual service projects. Tarpey (2022) showed that simulation and case teaching in project management courses helped students achieve significant improvements in organizational coordination and leadership development.

Autonomous learning ability and lifelong learning awareness are important learning outcomes mentioned in many studies. Prabhu et al. (2024) found that students showed higher initiative and participation in project-based flipped classrooms. Johnson and Ulseth (2016) confirmed that students have a stronger sense of learning engagement and autonomy in the new teaching system. Bill (2022) mentioned that the phased experiential project effectively improved students' self-confidence and practical ability.

In terms of comprehensive literacy, interdisciplinary integration ability is a significant achievement of practical teaching strategies. Luk et al. (2024) evaluated the impact of project-based learning on the cultivation of interdisciplinary skills of students majoring in biomedical engineering and found that the strategy effectively enhanced students' interdisciplinary collaboration ability.

Rehman's (2023) study showed that project-based learning promoted the integration of students' creative problem-solving skills and practical engineering thinking. Salinas-Navarro et al. (2023) confirmed that the integration of digital technology promoted students' sense of innovation.

Career preparation and engineering identity are important learning outcomes mentioned in many studies. Mesuwini et al. (2023) found that work-integrated learning experiences enhanced students' employment readiness. Senay's (2015) study showed that courses that integrate practical tasks and competency indicators are more popular with companies and help graduates quickly adapt to engineering positions. Johnson and Ulseth (2016) confirmed that systematic learning under project guidance promoted students' identification with engineering career paths.

Practice-oriented engineering education strategies are no longer limited to the cultivation of traditional technical skills, but are gradually shifting to cultivating well-rounded engineering talents with technical expertise, general abilities, and social responsibility. Different teaching strategies have different focuses on competency cultivation, but the overall trend is to develop in the direction of comprehensive competency cultivation. The literature also reflects the close connection between engineering competency cultivation goals and social needs and industrial changes, especially the increasingly prominent competency needs in digital transformation, sustainable development, and social responsibility.

Implementation Contexts and Influencing Factors

The analysis of the included literature revealed that the implementation effect of practice-oriented teaching strategies is closely related to the context, and multiple factors jointly affect the implementation process and final results of teaching innovation. These factors include institutional environment, resource conditions, teacher roles, industry participation, and regional culture.

Institutional environment and school characteristics are the basic conditions that affect the implementation of practical teaching strategies. Both studies by Johnson and Ulseth (2016, 2017) showed that engineering schools in the United States that adopted a reformed curriculum system successfully implemented student-centered project-based engineering education reforms through systematic institutional support.

Teacher roles and abilities have been identified as the key to the success of practical teaching by many studies. Salinas-Navarro et al. (2023)'s research clearly pointed out that the transformation of the teacher's role to a "guide" is the key driving force for the reform of engineering education in the digital age. Ajailia et al. (2024) found in their research on the implementation of the CDIO framework that teacher training is still the main difficulty in promoting AI ethics education. Gambheer and Acharya (2024) pointed out that the implementation of work-integrated learning requires teachers to have industry-university cooperation experience and project management capabilities. These studies show that teachers' teaching philosophy, professional background and teaching skills have an important impact on the implementation quality of practical teaching strategies, and teacher development and training have become a necessary condition to support innovation in practical teaching.

Industry participation is an important external factor affecting the implementation effect of practical teaching. Gambheer and Acharya (2024) emphasized that the depth of school-enterprise cooperation directly affects the implementation effect of work-integrated learning. Bolu et al. (2024) analyzed and pointed out that strengthening industry participation is a key path to improve the employability of engineering graduates. Mesuwini et al. (2023) also found that the quality of industry support and guidance has a significant impact on the effectiveness of work-integrated learning experience. Senay (2015) found through the analysis of graduate and employer survey data that course design closely connected with enterprise needs is more conducive to graduate employment. These studies show that the active participation of the industry provides real problems, professional guidance and internship opportunities for practical teaching, and is an important external support system for the successful implementation of practical teaching strategies.

Course design and integration methods have a direct impact on the effectiveness of practical teaching. Soska et al. (2014) found that modular structure helps to quickly adjust the teaching content of software engineering and focus on skill application. Raut et al. (2024) found that multi-stage project design enhances students' global understanding of the design process. Bill (2022) pointed out that the experiential learning module throughout the four years of undergraduate studies can systematically cultivate the capabilities of engineering students.
Under different educational backgrounds and resource conditions, the implementation paths and effects of practical teaching strategies vary, which suggests that engineering education practitioners need to adjust implementation strategies according to specific situations rather than simply copying successful experiences. The literature also reflects that with the changes in the educational environment and the development of technology, the implementation context of practical teaching is also constantly evolving, especially new implementation contexts in the context of digital transformation and globalization are being formed, providing new possibilities for the innovative application of practical teaching strategies.

Discussion

Engineering education is undergoing a profound transformation from traditional knowledge indoctrination to competence-oriented education. The diversity of practice-oriented teaching methods reflects the response to complex educational goals. From project-based learning, work-integrated learning to service learning, from experiential teaching to technology-enhanced practical teaching, these methods are different in form but essentially the same -

they are all committed to connecting theory and practice and cultivating engineering talents that adapt to the times. This diversity has its educational rationale: different teaching methods are suitable for different learning goals and learner characteristics. For example, project-based learning is particularly suitable for developing comprehensive design capabilities and teamwork, while work-integrated learning has unique advantages in connecting campus learning with professional practice. These multiple choices provide educators with a wealth of teaching tools, enabling them to choose appropriate teaching strategies for specific situations.

It is worth noting that these teaching methods are not isolated from each other, but show a trend of integration and innovation. The study found that many innovative cases integrated the advantages of different teaching strategies, such as Prabhu et al. (2024) combined flipped classrooms with project tasks, Salinas-Navarro et al. (2023) integrated digital technology and design thinking, and El Achkar and Alsaba (2024) integrated digital humanities with engineering education. This strategic integration reflects the systematic thinking on the cultivation of complex engineering capabilities, and also shows that practical teaching is developing in a more personalized and contextualized direction.

From the perspective of time development, engineering education reform presents several key trends. The first is the shift from decentralized practice to systematic cultivation. Early practical teaching was often limited to a single course or experimental link, while the current reform emphasizes the ability development system throughout the entire training process, such as Bill (2022)'s experiential learning module throughout the four years of undergraduate studies and Johnson and Ulseth (2016, 2017)'s systematic project-based curriculum system. This shift reflects the emphasis on the continuity of ability cultivation and helps to form a more consistent learning experience.

The second is the expansion from a closed classroom to an open ecosystem. Many practical cases in the study emphasize the deep connection with the outside world, especially the industry, such as the school-enterprise cooperation mechanism discussed by Gambheer and Acharya (2024) and the service-learning internship studied by Bermúdez et al. (2024). This open environment enables students to apply knowledge in real scenarios and promotes the connection between educational institutions and social needs. This trend is consistent with the current theory that emphasizes situational learning and reflects the pursuit of the social relevance of engineering education.

The third is the expansion from technical training to holistic education. The study found that contemporary practical teaching not only focuses on traditional engineering skills, but also pays more attention to comprehensive qualities such as social responsibility, ethical awareness, and sustainable development, such as Vanoye-Garcia and Menchaca-Torre (2024) on sustainable development capabilities and Ajailia et al. (2024) on AI ethics education. This expansion reflects the deepening of the understanding of the role of engineers and embodies the concept of shifting from training technical experts to training responsible citizens.

In addition, the impact of digital transformation on engineering education practice is also very obvious. The study involved a number of teaching cases enhanced by digital technology, such as the automated data acquisition system studied by Anderson (2019) and the application of digital tools analyzed by Dæhli (2016). Digital technology not only changes the way of learning as a teaching method, but also redefines engineering capabilities as the content itself. This is particularly important in the current wave of digitalization, providing new possibilities for innovation in engineering education.

These development trends constitute a dynamic picture of engineering education reform, reflecting the evolution of educational concepts and changes in social needs. However, it should be pointed out that the effect of practical teaching strategies is context-dependent, and the most effective teaching strategies may vary significantly under different educational backgrounds and resource conditions. This is of great significance for guiding engineering education practice: educators need to make reflective choices and innovative adjustments based on specific situations, rather than simply copying successful experiences.

Contemporary engineering competence training has gone beyond the purely technical level and expanded to three major areas: technical professional competence, general competence, and comprehensive literacy. This composite competence view is in sharp contrast to traditional engineering education, indicating that the recognition of engineers' roles is deepening. This puts forward new requirements for teaching design: a single-dimensional teaching method is no longer sufficient to meet the needs of composite competence training, and a more systematic teaching plan needs to be designed.

Research has confirmed that different teaching methods have unique advantages in cultivating specific abilities. Project-based learning is particularly good at cultivating systematic thinking and design capabilities, as shown in the research of Rehman (2023) and ElZomor et al. (2018); service learning is outstanding in developing social responsibility and communication skills, as confirmed by the research of Bermúdez et al. (2024); and work-integrated learning has obvious advantages in strengthening career preparation, and the analysis of Mesuwini et al. (2023) supports this conclusion. These differences indicate that teachers should choose teaching methods in a targeted manner according to the training objectives.

It is worth noting that the most successful teaching cases usually adopt comprehensive teaching designs. The project-driven learning model introduced by Johnson and Ulseth (2016, 2017) integrates multiple teaching elements, and the experiential learning designed by Bill (2022) runs through the entire training process. This shows that the formation of complex engineering capabilities requires long-term, coherent learning experiences and a diverse practice environment, and a single course or independent activity is difficult to achieve the expected results.

The study also emphasized the importance of consistency between capability development and evaluation. Tarpey's (2022) study showed that the design of evaluation tools in project management courses directly affects the development direction of students' soft skills. This highlights the principle of "constructive alignment": educational goals, teaching activities and evaluation methods should form a coordinated system.

From a time dimension, capability development is a gradual development process. Bill's (2022) study showed how four-year experiential learning can systematically cultivate engineering capabilities, and Johnson and Ulseth (2016) analyzed the role of long-term project learning in promoting the identity of the engineering profession. This shows that capability development requires strategic planning and the design of a coherent development path from admission to graduation.

Current engineering education faces the challenge of balancing traditional skills and emerging capabilities. The AI-related capabilities discussed by Vinod and Guile (2024), the sustainable development capabilities focused on by Vanoye-Garcia and Menchaca-Torre (2024), and the digital humanities integration capabilities studied by El Achkar and Alsaba (2024) all reflect changes in the engineering practice environment. The key challenge is how to balance these new and old capability requirements with limited resources.

Research shows that there is a dynamic relationship between capability training goals and industry needs. Senay (2015) compared the degree of match between graduate readiness and industry needs, and Bolu et al. (2024) analyzed the relationship between education reform and employability. This shows that engineering education needs to establish a mechanism to regularly update capability training goals and strengthen communication and cooperation with the industry and society.

From the perspective of educational philosophy, the research results show that engineering education is shifting from a "transmission model" to a "participation model". Salinas-Navarro et al. (2023) pointed out that the transformation of the teacher's role to a "guide" is the key to educational reform in the digital age. This deep-level change requires coordinated adjustments in educational philosophy, institutional structure, and evaluation system.

Conclusion

This systematic literature review comprehensively explores the application status, ability training effect and adaptive mechanism of practice-oriented teaching strategies in engineering education in different implementation scenarios through the analysis of 30 high-quality research papers. The research results provide a systematic perspective for us to understand the reform trend and practice path of contemporary engineering education, and also provide important inspiration for future educational innovation.

Regarding the practice-oriented teaching strategies (RQ1) currently used in engineering and technology education, this study identified a variety of teaching strategies, including project-based learning, work-integrated learning, service learning, experiential teaching, flipped classroom, case and simulation teaching, digital technology-enhanced practical teaching, multidisciplinary integrated teaching, and modular and iterative teaching. Although these strategies differ in form and implementation methods, they are all committed to narrowing the gap between theory and practice and closely integrating learning situations with real engineering practice. The study also found that these teaching strategies are undergoing a transformation from fragmented application to systematic integration, from closed classrooms to open ecology, and from single technical training to holistic education, reflecting the profound evolution of engineering education concepts.

Regarding the student abilities and learning outcomes that these teaching strategies aim to cultivate (RQ2), the study shows that practice-oriented teaching strategies aim to cultivate multi-dimensional composite engineering abilities, including technical professional abilities (such as practical engineering skills, system thinking and design abilities), general abilities (such as communication and collaboration, critical thinking, leadership and autonomous learning abilities), and comprehensive qualities (such as interdisciplinary integration abilities, social responsibility and ethical awareness, innovation abilities and professional identity). Different teaching strategies have differentiated advantages in cultivating specific abilities, but the overall trend is to develop in the direction of comprehensive ability cultivation. The ability cultivation effect often comes from the synergy of multiple teaching strategies and long-term, coherent learning experiences, which indicates that engineering education needs to rethink the overall path of ability cultivation from a system level.

Regarding the contextual factors that affect the implementation and effectiveness of teaching strategies (RQ3), the study revealed the strong contextual dependence of practical teaching effectiveness, and multiple factors jointly shape the success or failure of teaching practice. Institutional environment and policy support, resource conditions and utilization efficiency, teacher role transformation and capacity development, industry participation depth and quality, student characteristics and readiness, implementation timing and process design, regional and cultural differences, evaluation system and feedback mechanism and other factors are interrelated and constitute a complex teaching ecosystem. This situational sensitivity reminds us that engineering education innovation cannot simply copy successful experiences, but needs to be adaptively adjusted and creatively implemented according to specific situations. Establishing a supportive institutional environment, providing sufficient resource support, promoting teacher role transformation, deepening industry-education cooperation, paying attention to student diversity, optimizing time planning, respecting cultural differences, and reforming the evaluation system are all key strategies to improve the effectiveness of practical teaching.

Regarding the evaluation method of learning outcomes (RQ4), the study shows that engineering education evaluation is undergoing a transformation from traditional single evaluation to multiple and comprehensive evaluation, from terminal evaluation to formative evaluation, from teacher-led to multi-subject participation, and from focusing on result verification to focusing on process improvement. This evaluation change reflects a deeper understanding of the complexity of the capacity development process and the nature of learning, and also lays the foundation for establishing an evidence-oriented teaching culture. However, the study also found that current evaluation practices face challenges such as the development of evaluation standards, improvement of evidence quality, application of digital technology, ecological validity assurance and system integration, which need to be addressed in future research.

Although this study has achieved the above results, there are still some limitations. First, the number of included literature is limited, and it may not fully cover all relevant studies. Second, there is a certain imbalance in the geographical distribution and subject coverage of the literature, which may affect the universality of the conclusions. In addition, the long-term impact on teaching effectiveeness and the analysis of differences in different contexts need to be further deepened.

Based on the findings and limitations of this study, future research can be further expanded in the following directions: conduct more follow-up studies on the long-term effects of practical teaching to evaluate its continued impact on career development; deeply explore the adaptive mechanisms of practical teaching in different cultural and educational backgrounds, and provide more context-specific implementation guidelines; strengthen evaluation methodology research and develop more scientific and effective competency evaluation tools and frameworks; explore the deep integration of digital technology and practical teaching to cope with the opportunities and challenges brought about by digital transformation; study institutional-level change strategies to reveal how to build an organizational environment and institutional mechanisms to support innovation in practical teaching.

The contribution of this study at the theoretical level is mainly reflected in the construction of a systematic classification framework of practice-oriented teaching strategies, revealing the multi-dimensional composite structure of engineering ability training, and clarifying the inherent correlation mechanism between teaching strategies and ability development. Based on constructivist learning theory and contextual learning theory, the study established the theoretical view that "practice-oriented teaching is the core driving force for the development of engineering capabilities", providing a theoretical basis for the transformation of engineering education from the traditional knowledge transfer model to the ability training model. At the same time, through a systematic analysis of implementation context factors, this study enriched the theory of engineering education ecosystem and emphasized the importance of the synergy of multiple factors such as institutional environment, teacher roles, and industry participation.

In terms of contextual significance, this study directly responds to the real challenges of digital transformation, sustainable development, and social responsibility faced by global engineering education. The teaching strategy types and implementation paths identified in the study provide evidence-based guidance for curriculum reform and teaching innovation in engineering colleges, especially in key areas such as project-based learning, industry-university integration, and interdisciplinary integration. The contextual adaptability principle emphasized in the study provides differentiated implementation strategies for engineering education reform under different cultural backgrounds and resource conditions, which helps to promote localized innovation in global engineering education. In addition, this study's analysis of the changing trends in evaluation methods lays the foundation for establishing a more scientific and comprehensive engineering competency assessment system and supports the continuous improvement of the engineering education quality assurance system.

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