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Application of Industry-Education Integration Model in Vocational Education: A Systematic Literature Review of Learning Factories and Industrial Colleges

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Abstract

This study analyzes the role of learning factories and industrial colleges in improving the quality of vocational education through a systematic literature review. The results show that learning factories simulate real production environments, enabling students to learn and master skills in practice, significantly improving their practical ability and professional quality; while industrial colleges cultivate high-quality application-oriented talents that meet industry needs through in-depth school-enterprise cooperation and resource sharing. However, the study also found that these two models face many challenges in the implementation process, such as insufficient funding and resource investment, high technical complexity, and weak teaching staff. In response to these challenges, this paper proposes suggestions such as strengthening funding, improving teaching staff, deepening school-enterprise cooperation, reforming the curriculum system, and improving the management system, so as to optimize the construction path of learning factories and industrial colleges and further improve the quality of vocational education and students' employability.

Keywords: Learning Factory, Industrial College, Vocational Education, Industry-Education Integration, School-Enterprise Cooperation, Technical Skills Training

Introduction

Vocational education plays a key role in modern economic and social development. It is an important part of cultivating technical and skilled personnel, improving the quality of workers, promoting employment and promoting economic development. General Secretary Xi Jinping emphasized at the National Vocational Education Work Conference that we should

innovate the vocational education models at all levels and types, adhere to the integration of production and education, school-enterprise cooperation, and adhere to the combination of work and study, and the unity of knowledge and practice(Agency, 2014).This has pointed out the direction for the reform and development of China's vocational education.

As two important models of industry-education integration, learning factories and industrial colleges have shown remarkable results in improving the quality of vocational education, promoting student employment and serving regional economic development in recent years. However, the advantages, challenges and specific construction paths of these two models in practical application still need in-depth research. This study aims to systematically explore the main role of learning factories and industrial colleges in vocational education, the advantages and challenges in the implementation process, and their effects in improving the quality of vocational education and promoting employment.

Specifically, this study will analyze how learning factories can improve students' practical skills and professional qualities by introducing a production environment, and how industrial colleges can cultivate compound high-quality talents through school-enterprise cooperation by integrating teaching, practical training and scientific research. At the same time, the study will also explore the main challenges faced by these two models in the implementation process, such as facilities and equipment, teaching staff, student participation, depth of school-enterprise cooperation, curriculum setting and transformation of scientific research results. Finally, this study will evaluate the specific results of learning factories and industrial colleges in improving the quality of vocational education and promoting employment, and put forward suggestions for optimizing the construction paths of these two models.

Through a systematic literature review, this study will compare the roles of learning factories and industrial colleges in vocational education and their construction paths, revealing the characteristics and effects of the two models. The research results not only provide empirical evidence and specific guidance for vocational colleges to select and optimize the industry-education integration model, but also provide a reference for governments and education managers to formulate vocational education policies and promote the reform and development of vocational education.

Literature Review

The literature review aims to systematically review and analyze the definition, origin, development history and application status of learning factories and industrial colleges in order to provide theoretical support and background information for this study.

Definition and Development of Learning Factory

Definition

According to the literature(Hvidsten et al., 2022)， the CIRP[1] Collaborative Working Group defined and published the term learning factory in the CIRP Encyclopedia(Chatti et al., 2019) as follows:

- A real process, including multiple sites, including technical and organizational aspects,
- A variable environment, similar to a real value chain,

[1] CIRP The International Academy for Production Engineering

- A physical product being manufactured, and
- A teaching concept that includes formal, informal and non-formal learning, which is achieved by learners through their own actions in a live learning method.

Abele et al. also believe that this can be regarded as a learning factory in a narrow sense, while some extensions (digital, remote and non-physical products) can be regarded as learning factories in a broad sense(Abele et al., 2019).

Origin and Development History

The concept of a learning factory can be traced back to the CIM[2] Learning Factory(Reith, 1988), established in Germany in the late 1980s, but it was not well known at the time. According to the research of Abele et al. (2024) , the development of a learning factory has gone through four stages:

In the first stage (1990s), learning factories in the United States, such as the Learning Factory at Penn State University, emphasized practical experience and interdisciplinary hands-on learning through engineering learning and industry-cooperative engineering design projects(Abele et al., 2024; Lamancusa et al., 1995). In the second stage (2000), in the 21st century, the concept of learning factories began to emerge in Europe and grew rapidly(Abele et al., 2015; Micheu & Kleindienst, 2014; Wagner et al., 2012) , covering different fields and target groups, such as the Center for Production Learning Factory (CiP) of the Technical University of Darmstadt in Germany(Abele et al., 2007) . In the third stage (2010), academia and industry began to strengthen cooperation to jointly promote the research and application of learning factories, and established the European Learning Factory Initiative (IELF), the Network of Innovative Learning Factories (NIL) and the CIRP Collaborative Working Group(Abele et al., 2024) . In the fourth stage (2017 to present), learning factories have shown a global trend, and the establishment of the International Association of Learning Factories (IALF) marks its global recognition and promotion. The Learning Factory Conference attracted global participants to discuss future development directions (Abele et al., 2024).

In summary, the learning factory has gone through a long journey from its initial rise to its current global development. It has not only changed the traditional education model, but also provided a new training and research platform for the industry. With the continuous advancement of technology and the continuous expansion of application scenarios, the learning factory will play an increasingly important role in the future.

Application Status

At present, learning factories have been widely used in vocational education and training in many countries. In the past five years, literature [12-28] introduced some cases of learning factories and demonstrated the characteristics of learning factories in improving students' skills training.

[2] CIM Computer Integrated Manufacturing

Application Case	Country /Region	Application Specialties	Features
Collaborative Learning Factory(Ziarsolo et al., 2023)	Europe (Germany, Spain, etc.)	Collaborative product design and manufacturing; cross-border project cooperation; robotics, 3D printing, artificial intelligence, and Internet of Things technical skills training.	Internationalization (comprising training centers from 7 different countries), collaboration, technological advancement and pedagogical innovation make it a unique educational platform that can provide a rich learning experience and development opportunities for higher vocational education students
Cooperation in learning factory courses between TU Darmstadt (TUDa), Ruhr University Bochum (RUB) and Reitlingen University (ESB) (Enke et al., 2020)	Germany	Information support systems, technical support systems, industrial employment impact (RUB); industrial impact, digital indicators, problem solving methods (TUDa); smart logistics, digital engineering, additive manufacturing (ESB)	Cross-school and cross-disciplinary cooperation, practical operation in real scenarios
Center for the use of digital technologies in teaching (CIU) Learning Factory(Lindvig & Mathiasen, 2020)	Denmark	Virtual reality (VR) teaching applications, augmented reality (AR) theory visualization, learning management system (LMS) knowledge sharing, online learning environment optimization, digital transformation strategy formulation	Immersive learning experience, visualization of theoretical knowledge, cross-platform knowledge sharing, optimization of learning process, digital transformation of teaching
UCN Industrial Playground (UCN IP) Learning Factory at the University of Northern Denmark (Grøn et al., 2020)	Denmark	Automation technology, production planning and control, quality management, supply chain management, information system, digital twin technology, intelligent manufacturing	High adaptability, modular design, high degree of automation and informatization
Royal Institute of Technology （KTH）Lean Manufacturing Lab (LML) Learning Factory (Monetti et al., 2023)	Sweden	Production Engineering, Lean Manufacturing	Strong practicality, problem-oriented, teamwork, application of lean tools, reflective learning
IdeaLab Learning Factory (Kleppe et	Norway	Industry 4.0, Automation, Lean Manufacturing	Multidimensional model, digital infrastructure, flexibility and

Application Case	Country /Region	Application Specialties	Features
al., 2022; Vijayan & Mork, 2020)			variability, openness and collaboration
Industry 4.0 Learning Factory (Scholz et al., 2020)	China	Smart manufacturing, industrial Internet, big data analysis	Cross-industry and cross-stage training, flexible and adaptable, agile development, mobile learning games, dual hybrid project management
Learning Factory of Zhejiang University School of Micro and Nano Electronics (Xu et al., 2023)	China	Chip design and manufacturing	Full-process practice, advanced facilities, professional R&D team, integration of industry, academia and research
AMTC Learning Factory (Zhang et al., 2020)	China	Mechanical Engineering	Emphasis on the application of 5G and AI technologies, combining AI, big data, cloud computing and domain knowledge, adopting role-playing learning methods, and advanced experimental facilities
FIM Learning Factory (Maarof, 2020; M. Maarof & M. Bohari, 2023; M. Maarof & M. Z. Z. Bohari, 2023)	Malaysia	Lean Management Skills	Simulate real production environment, practical learning, variable production line, group cooperative learning, focus on soft skills training
University of Twente Learning Factory (Damgrave et al., 2023)	Netherlands	Industrial Engineering, Mechanical Engineering, Industrial Design Engineering, Computer Science, Artificial Intelligence and Robotics, Management Science and Engineering	Project-driven, multidisciplinary integration, recursive apprenticeship learning, virtual reality and augmented reality, dynamically changing environment. Improve learning motivation and participation, cultivate critical thinking and problem-solving skills, and promote collaborative learning ability
Smart Factory Zagreb (Nixdorf et al., 2023)	Croatia	Teaching, training and R&D of Industry 4.0 related technologies	Use modern technology and equipment, online and offline hybrid teaching, cultivate Industry 4.0 talents, and promote the digital transformation of enterprises
CSIR (South African Council for Scientific and Industrial Research)	South Africa	Human-computer interaction, augmented reality, robotics, additive manufacturing (3D printing), Internet of	Industry driven, skills training, innovation support, smart factory, collaborative robots

Application Case	Country /Region	Application Specialties	Features
Learning Factory (Gopal, 2022)		Things, smart applications	
Advanced Manufacturing Research Centre (AMRC) Factory 2050 (Edwards, 2021)	England	Automated assembly, intelligent integration, digital manufacturing, robotics, metrology, AI, information technology	Industrial drive, university research, multidisciplinary team, apprentice innovation ambassador
Warwick Manufacturing Group (WMG) Digital Skills Factory (Edwards, 2021)	England	Digital manufacturing, intelligent manufacturing, digital twins, cyber-physical systems, data management and knowledge representation	Integration of R&D, teaching and training, coexistence of traditional and advanced technologies, mobile equipment packages, and integration of data systems and physical equipment
Cyber-Physical Learning Factory (Edwards, 2021)	England	Control technology, smart factory technology, mechatronics, material flow, system networks, information flow, process planning, assembly and disassembly planning, data processing systems.	Collaborative networks, practice orientation, regionalization, community involvement
Institute of Advanced Manufacturing and Engineering (AME) Factory (Edwards, 2021)	England	Industry 4.0, Digital Manufacturing and Simulation, Automation and Control, Metrology and Measurement Uncertainty, Surface Engineering, Wearables, Lasers, Welding and Joining	Real manufacturing environment, industrial/academic partnership, skills value chain, supply chain integration, shared learning resources
National Centre for Food Manufacturing (NCFM) Learning Factory at the University of Lincoln (Edwards, 2021)	England	Food science, food technology, manufacturing practices, food processing, packaging, supply chain management, food safety, quality management, new product development	Industry-university collaboration, multi-channel funding, hybrid teachers (dual-qualified teachers), apprentice innovation ambassadors, hybrid delivery models

Definition and Development of Industrial Colleges

Definition

Industrial colleges are new educational institutions jointly built, managed and shared by the government, universities, industries and enterprises(Wang et al., 2021) . They aim to cultivate high-quality applied, compound and innovative technical and skilled talents who can adapt to and lead the development of modern industries through in-depth school-enterprise cooperation and the integration of industry and education(Jiao & Li, 2021; Li et al., 2022) .

They are usually based on disciplines or majors, and have the characteristics of resource sharing, mutual benefit and win-win, independent operation and clear service objects(Shanna, 2023; Sun & Sun, 2020; Wang et al., 2021) . With the deep participation of industries and enterprises, they are guided by customers and production chains, product chains, technology chains and service chains(Lu et al., 2020) . They are usually jointly built and managed by local governments, universities and industrial enterprises, aiming to cultivate high-quality applied talents and guided by industry needs, and carry out talent training, scientific research and social services(Wang et al., 2022; Yuan & Li, 2020; Zhang et al., 2022).

Industrial colleges are an important platform for the integration of production and education and school-enterprise cooperation in vocational colleges. They are not only conducive to giving full play to the original functions and advantages of vocational colleges, but also can give full play to the innovation advantages of enterprises, promote the two-way integration of supply and demand, enhance the adaptability of vocational education development, and improve the quality of vocational education talent training. (Wu & Cui, 2023).

Origin and Development History

In the early 21st century, the Chinese Industrial College appeared again. In 2007, scholars from Zhejiang Vocational and Technical College of Economics in China mentioned the theme of "Industrial College" in their research literature and summarized the school's practical experience in cultivating talents in a collaborative way between industry, academia and research. (Wang, 2023). In December 2017, the General Office of the State Council of China issued the "Several Opinions on Deepening the Integration of Industry and Education"(China, 2017) , marking the official introduction of the term “industrial college”. In October 2021, the “Opinions on Promoting the High-Quality Development of Modern Vocational Education” issued by the General Office of the CPC Central Committee and the General Office of the State Council proposed “promoting the joint construction and management of industrial colleges and enterprise colleges by schools and enterprises, and extending the space for vocational schools to run schools”(China, 2021). With the gradual development of the policy of industry-education integration, industrial colleges have been widely promoted in China’s vocational education system and have become a new hot spot for academic research in the field of education(Wang, 2023) . However, China’s research on industrial colleges is still in the exploratory stage(Li et al., 2022).

Application Status

According to the research literature in the past five years (2020-2024), the research on industrial colleges mainly focuses on the empirical analysis of industry-education integration, implementation mechanism, talent training, cooperation model, operation model and practical effect. The actual application cases of industrial colleges in the English research literature in China show that this model can better cultivate high-quality talents who can adapt to industrial development, improve students' practical operation ability and employment competitiveness, and effectively promote the connection between vocational education and enterprise needs(Gao, 2023; Shanna, 2023). Literature(Gao, 2023; Guo & Yang, 2024; C. Han, 2023; Shanna, 2023; Wang, 2021) provides some specific application cases to demonstrate the effectiveness of industrial colleges in actual operation.

Application Case	Country /Region	Application Specialties	Features
College of Agriculture and Animal Husbandry (Wang, 2021)	China	Animal husbandry, agricultural machinery, agricultural product processing	Industry-oriented, school-enterprise cooperation, local service, integration of industry, academia and research
Blue Future Special Education Industry College (Guo & Yang, 2024)	China	Rehabilitation education for autistic children in the field of special education	School-enterprise cooperation, practice orientation, digital empowerment
Rural Revitalization E-commerce Industry College (C. Han, 2023)	China	Rural e-commerce	Industry-education integration, flexible teaching, and sending education to the countryside
Phoenix Industrial College (Gao, 2023)	China	New Media Operations	Relying on the resources of Phoenix Education Group, we conduct project-based teaching and company-based training
College of Elevator in South Zhongshan District (Shanna, 2023)	China	Elevator engineering technology, elevator installation and maintenance	Established in the national Torch Elevator Specialty Industrial Base, it cooperates with the government, research institutes, industry associations and other parties. It has a complete training base and teaching staff to cultivate high-quality elevator engineering and technical talents.
Shaxi Textile and Garment College (Shanna, 2023)	China	Textile Engineering, Fashion Design and Technology, Fashion Marketing	Established as a leisure clothing production base in China, we cooperate with local governments, industry associations, enterprises and other parties, focus on cultivating students' practical and innovative abilities, and provide talent support for the development of the textile and garment industry.
Guzhen Lighting College (Shanna, 2023)	China	Lighting design, lighting engineering, lighting product research and development	Established in China's lighting decoration base, it cooperates with local governments, industry associations, enterprises and other parties. It has advanced lighting laboratories and training equipment to cultivate high-quality lighting professionals.
Xiao Lan College (Shanna, 2023)	China	E-commerce, marketing, modern logistics	Established on a national-level industrial cluster base, the school cooperates with local governments, industry associations, enterprises and other parties, focuses on cultivating students' professional skills and entrepreneurial abilities, and provides talent support for the development of the modern service industry.

Relevant Theoretical Basis

Although the learning factory originated abroad and the industrial college model is mainly in China, both models are built on the same educational theory.

Theory of Industry-Education Integration

Industry-education integration is an important direction for the development of vocational education. It can effectively improve students' professional skills and employment competitiveness(Gao, 2023) , but it is also a complex concept. Industry-education integration is a process that promotes the deep integration of talent training and industrial demand(China, 2017) , emphasizes the principle of school-enterprise cooperation, co-construction and sharing(China, 2019) , and is a process centered on market demand, industrial development, talent training, innovation and entrepreneurship, school-enterprise cooperation, and win-win cooperation(China, 2010) . In China, industry-education integration originated in the early days of reform and opening up, when the education department began to cooperate with the industry and gradually formed an important education model. With market changes and industrial upgrading, the forms and contents of industry-education integration have been continuously enriched, such as school-enterprise cooperation, industry-university-research integration, and international cooperation(Zuo et al., 2024). Literature(Roll & Ifenthaler, 2020; Sun & Sun, 2020; Wang et al., 2021) points out that industrial colleges and learning factories improve the quality of vocational education, cultivate applied talents, promote regional economic development, and meet the region's demand for high-quality applied talents through school-enterprise cooperation and industry-education integration.

Work-Based Learning （WBL）

Work-based learning refers to various methods of learning through work, including learning on the job, learning for work, and learning through work(Lemanski et al., 2010) . It allows students to be exposed to real or simulated work environments and apply the technical knowledge and skills learned in the classroom to real environments(Colquhoun & Munro, 2007) , thereby gaining valuable practical experience. This model combines explicit and implicit knowledge at the individual and collective levels, such as professional skills, work experience, teamwork ability, etc., and emphasizes a learning model that combines theory with practice to cultivate students' proficiency and critical thinking ability(Raelin, 1997) . Reference(Milisavljevic-Syed et al., 2023) points out that learning factories usually adopt a work-based learning model. Reference(Nixdorf et al., 2023) also believes that learning factories are an effective way to implement work-based learning (WBL). These factories can provide a real working environment and advanced technology platforms to help students and workers master practical skills. For the manufacturing industry in Southeast Europe, especially in Croatia, work-based learning is crucial because it helps alleviate the problem of skill shortages and improve labor productivity. Through a work-based learning environment, students and workers can better understand and apply what they have learned.

Constructivist Learning Theory

References(Abele et al., 2024; Assad et al., 2020; Edwards, 2021; Enke et al., 2020; M. Maarof & Bohari, 2023; Monetti et al., 2023; Riemann et al., 2020; Riemann et al., 2021a; Rossmeissl et al., 2019; Widiaty et al., 2021; Yuan & Li, 2020; Zhang, 2023) point out that learning factories and industrial colleges adopt a practice-oriented teaching method by

constructing or simulating real factory environments to provide students with substantial operational experience. This model of integrating engineering knowledge aims to enhance students' practical ability and teamwork through participatory action and collaborative learning. This is consistent with the concept of constructivist learning theory(Wei, 2007) , which emphasizes that learning is an individual subjective and socialized process, and learners construct knowledge and understanding through active participation and interaction. Constructivist learning theory(Cooperstein & Kocevar-Weidinger, 2004; Ms, 2020) emphasizes process, participation and real-life experience, promoting learners to construct personal meaning, build new knowledge on previous knowledge, and deepen understanding through social interaction and real tasks.

Overview of Related Research at Home and Abroad

Learning Factory

Domestic Research

In the past five years, research on learning factories in China has mainly focused on the integration of teaching methods and practical skills, digital technology and intelligent manufacturing, and sustainable development and education. First, the research focuses on bridging the gap between theory and practical skills, proposing new teaching methods based on student-laboratory interaction to improve teaching effectiveness and student satisfaction, while emphasizing the balance between physical environment and industry participation(Lugaresi et al., 2023; Xu et al., 2023) . Second, in terms of digital technology and intelligent manufacturing, the application of digital twin technology in learning factories is studied, especially ontology-based methods to support workshop digital twin configuration, data-driven quality analysis methods are developed and verified through learning factories, and the application of 5G and AI technologies in learning factories is explored, emphasizing their importance for data transmission and real-time analysis(Yang et al., 2020; Yang et al., 2023; Zhang et al., 2020) Finally, research on sustainable development and education explores the impact of learning factories on education and sustainable development, emphasizing the cooperation between academia and industry to cultivate a future workforce that adapts to sustainable development goals(Jing et al., 2023) . These studies have not only made progress in the integration of teaching methods and practical skills, but also demonstrated significant results in the application of digital technology and sustainable development education.

The cases in the literature(Scholz et al., 2020; Xu et al., 2023; Zhang et al., 2020) show that the learning factory is an effective talent training model for the manufacturing industry. It can help students learn and master new technologies in practice, improve their practical ability and problem-solving ability, cultivate their sense of innovation and teamwork ability, and provide talent guarantee for the sustainable development of the manufacturing industry.

Foreign Research

In the past five years, foreign research on learning factories has mainly focused on the combination of teaching methods and practical skills, digital technology and intelligent manufacturing, sustainable development and education, and interdisciplinary and transnational cooperation. The research emphasizes the combination of theory and practical skills, using technologies such as virtual reality and augmented reality to improve the teaching environment, improve teaching effectiveness and student satisfaction(Al Khatib et al., 2023;

Lindvig & Mathiasen, 2020) . In terms of digital technology and intelligent manufacturing, the application of digital twin technology, 5G and AI technology in learning factories is discussed, emphasizing their importance for data transmission and real-time analysis, and using virtual reality technology to adapt to the complexity of industrial production environments(Gopal, 2022; Nellemann et al., 2022; Riemann et al., 2020; Riemann et al., 2021a, 2021b) . In terms of sustainable development, learning factories such as the Danish MADE program support lifelong learning and emphasize the integration of the concept of Industry 4.0 in vocational and technical education institutions(Nellemann et al., 2022; Srivastava et al., 2022) . In addition, learning factories have also promoted interdisciplinary and transnational cooperation. For example, the European Commission's COVE project supports advanced manufacturing and higher vocational education and training through collaborative learning factories, and the International Association of Learning Factories (IALF) improves learner skills through information exchange and joint projects(Enke et al., 2020; Ziarsolo et al., 2023) . These studies have not only made progress in the combination of teaching methods and practical skills, but also demonstrated remarkable results in the application of digital technology and sustainable development education. At the same time, they have promoted interdisciplinary and cross-national cooperation, providing valuable experience and inspiration for the future development of industry and education.

At present, foreign research on learning factories is mainly concentrated in the following countries and fields. Denmark uses learning factories to solve recruitment and personalized teaching problems, and improves the teaching environment through virtual reality and augmented reality technologies(Lindvig & Mathiasen, 2020; Nellemann et al., 2022). Germany has conducted extensive research on virtual reality, digital twin technology and interdisciplinary cooperation, and applied them in the context of Industry 4.0(Enke et al., 2020; Gopal, 2022; Riemann et al., 2020; Riemann et al., 2021a, 2021b) . The European Commission's COVE project supports several countries (such as Germany and Denmark) to promote technology implementation and international cooperation through collaborative learning factories(Ziarsolo et al., 2023) . Norway studies interdisciplinary learning and sustainable development through NTNU's IdeaLab project (Kleppe et al., 2022; Vijayan & Mork, 2020) . Croatia and Southeast Europe emphasize the application of work-based learning (WBL) and its role in rapid transformation (Nixdorf et al., 2023) . Malaysia explores the effect of learning factories on improving students' practical skills and interests (Maarof, 2020; Maarof & Bohari, 2023; Maarof & Bohari, 2023) . India studies the adoption of Industry 4.0 learning factories in technical education institutions, emphasizing the importance of organizational dimensions(Srivastava et al., 2022). The International Association of Learning Factories (IALF) promotes information exchange and joint projects on learning factories among European countries(Enke et al., 2020). These studies have achieved remarkable results in the combination of teaching methods and practical skills, the application of digital technologies and education for sustainable development, and have promoted interdisciplinary and cross-border cooperation.。

Industrial College

Domestic Research

From the English research literature on industrial colleges in the past five years, it can be seen that China's current research on industrial colleges mainly focuses on policy innovation, operation mode, rural vocational education, evaluation system, talent training, school-

enterprise cooperation and digital economy. First, as a specific form of industrial education integration and in-depth school-enterprise cooperation, industrial colleges explore their operation mode and mechanism through policy innovation, education innovation and technological innovation, and promote the operation of industrial colleges supported by vocational education groups through functional coupling, resource integration and benefit sharing (Lu et al., 2020; Shanna, 2023). The study explored the problem of shortage of rural vocational education resources and its disconnection with rural industrial needs, and proposed the construction path of rural revitalization industrial colleges to serve the national rural revitalization strategy and the policy of expanding enrollment in higher vocational colleges (Han, 2023). In addition, an evaluation index system for the implementation mechanism of industrial colleges based on the balanced scorecard (BSC) theory was established, a hybrid teaching quality evaluation model was constructed, and the implementation effect of industrial colleges was comprehensively evaluated through qualitative and quantitative analysis methods (Li, 2024) . The study analyzed the importance of industrial colleges in the cultivation of applied talents and proposed the basic path and steps for construction to enhance the application-oriented school-running capabilities of local universities (Sun & Sun, 2020; Wang et al., 2021; Yuan & Li, 2020) . At the same time, it emphasizes school-enterprise cooperation and collaborative education, proposes an overall framework of industrial education alliances and professional groups, and improves the social service capabilities of vocational colleges through data analysis (Wang, 2021; Zhang et al., 2022; Zhu et al., 2021) . In the future, the development trend of industrial colleges includes giving full play to the role of vocational education groups and deeply integrating into the development of the digital economy (Han, 2023; Wu & Cui, 2023) . These studies provide theoretical support and practical guidance for the development of industrial colleges.

Related Foreign Models

Although there is little research on the industrial college model abroad, there are some similar international models that can provide valuable references.

The work-integrated learning (WIL) model is a learning model that combines academic learning with the workplace, aiming to improve students' professional skills through work experience (McDonald et al., 2019) . WIL mainly achieves the integration of learning and work through three methods: internships, simulations, and industrial projects. Internships allow students to enter the workplace for full-time or part-time learning, ranging from a few weeks to a few months. Simulations allow students to learn and be assessed in simulated real-life work situations, such as analyzing problems and making decisions. Industrial projects allow students to participate in actual work projects, such as product development, and work with industry partners. All of these methods help improve students' professional skills and employability (WORK-BASED).

Dual education is an educational model that combines theoretical learning with practical training and is widely used in vocational education and higher education (Kravchenko et al., 2023) . In vocational education, students not only learn theoretical knowledge in school, but also conduct practical learning in enterprises or workplaces, directly applying the knowledge they have learned to professional activities, thereby acquiring knowledge and skills related to their careers (Krymchak, 2019) . In the field of higher education, dual education combines theoretical teaching in higher education institutions with practical training in enterprises or

workplaces, aiming to cultivate high-quality talents with both theoretical knowledge and practical skills(Flek & Ugnich, 2019).

Research Methods

This study uses a systematic literature review method to analyze the role of learning factories and industrial colleges in vocational education and their construction paths. Based on the research topic, search keywords were formulated, namelyALL= ("learning factory" AND "vocational education")和 ALL= (" Industrial college " AND "vocational education") . Literature search engines are powerful tools. However, there are differences between these sources, and multiple engines should be used for systematic searches to ensure that all relevant data are obtained(Piper, 2013) . This study first used Scopus and Web of Science for literature retrieval, but due to the small number of documents, the Google Scholar database was added to retrieve open access English documents matching the search keywords between 2020 and 2024, and a total of 187 articles were identified.

On the basis of these results, we browsed through the articles according to their titles, keywords, abstracts and main conclusions, and manually screened out literature that was closely related to learning factories, industrial colleges and vocational education and had passed the peer review process in international academic journals, and finally identified 56 relevant publications.

Key information is systematically extracted from the included literature, including the research topics, research methods, research conclusions, as well as the definition, origin, main characteristics, operation mode, advantages in the implementation process, challenges faced, practical application cases of learning factories or industrial colleges in the literature, and the effects on improving the quality of vocational education.

The qualitative data extracted from the literature are analyzed and summarized using content analysis. The definition, development history, application status, role, advantages, challenges and construction path of learning factories and industrial colleges are classified and summarized, as well as their roles, advantages, challenges and construction paths in vocational education. This literature review is formed.

Research Results

Through a systematic review of the literature in the past five years, it is found that both learning factories and industrial colleges have significant effects in improving the quality of vocational education. Among them, the learning factory model has many practical cases around the world, and the industrial college model is a model of industry-education integration that China is currently promoting.

Learning factories have played an important role in improving the quality of vocational education and students' employment competitiveness. First, learning factories provide a more effective way of learning, helping students better master knowledge and skills, improve their interest in learning and hands-on ability, and thus reduce the student dropout rate(Lindvig & Mathiasen, 2020; Riemann et al., 2020; Riemann et al., 2021a, 2021b; Roll & Ifenthaler, 2020). Second, through school-enterprise cooperation and practical teaching, students have more practical opportunities, significantly improving their practical ability,

innovation ability and employment competitiveness (Guo & Yang, 2024; Hulla et al., 2021; Maarof, 2020; Maarof & Bohari, 2023; Milisavljevic-Syed et al., 2023; Nellemann et al., 2022; Nixdorf et al., 2023; Sudhoff et al., 2020) . In addition, learning factories have promoted the close integration of vocational education and industrial needs, promoted the connection between curriculum content and industrial needs, cultivated high-quality technical and skilled talents that meet the needs of enterprises, and enhanced the attractiveness of vocational education (Assad et al., 2020; Gopal, 2022; Monetti et al., 2023; Sudhoff et al., 2020; Wang et al., 2022; Widiaty et al., 2021; Zhang, 2023) . Learning factories have promoted the reform and innovation of vocational education and improved the overall quality of vocational education by simulating real production environments and integrating Industry 4.0 technologies (Al Khatib et al., 2023; Damgrave et al., 2023; Enke et al., 2020; Grøn et al., 2020; Kleppe et al., 2022; Scholz et al., 2020; Srivastava et al., 2022) . Finally, learning factories have also cultivated students' interdisciplinary and teamwork capabilities, promoted cooperation between schools and enterprises, and enhanced the social status and influence of vocational education (Hvidsten et al., 2022; Lutters & Damgrave, 2023; Maarof & Bohari, 2023; Skosana et al., 2023; Vijayan & Mork, 2020; Ziarsolo et al., 2023). Overall, these studies show that learning factories have played an important role in improving students' practical ability and employment competitiveness, promoting the integration of vocational education and industrial development, and improving the quality of vocational education (Lu et al., 2020; Shanna, 2023; Wang, 2021; Wu & Cui, 2023; Zhang et al., 2022).

Industrial colleges have achieved remarkable results in improving the quality of vocational education and promoting regional economic development. First, industrial colleges have promoted the organic connection of the education chain, talent chain, industrial chain and innovation chain, formed a system to ensure the quality of talent training, improved the pertinence of talent training, and cultivated more skilled talents that meet the needs of enterprises (Lu et al., 2020; Wu & Cui, 2023) . Second, through school-enterprise cooperation and practical teaching, industrial colleges have significantly improved students' practical ability and ability to solve practical problems, and enhanced students' employment competitiveness (Guo & Yang, 2024; Shanna, 2023; Yuan & Li, 2020) . At the same time, industrial colleges have promoted the construction of the curriculum system, closely integrated the curriculum content with industrial needs, and cultivated more "dual-qualified" teachers, optimizing the teaching staff (Shanna, 2023; Wang et al., 2022) . In addition, industrial colleges have also promoted the deep integration of vocational education and industrial development, providing strong support for regional economic and social development (Wang et al., 2021; Wang, 2021) . In short, industrial colleges have achieved remarkable results in improving the quality of vocational education, optimizing talent training models and promoting regional economic development (Zhang, 2023; Zhang et al., 2022).

However, both the learning factory model and the industrial college model face a series of challenges in the implementation process, especially in terms of capital and resource investment, technical complexity, teaching staff, school-enterprise cooperation, management operation, curriculum development and reform, etc.

Challenges	Learning Factory	Industrial College
Funding and resource investment	Building and maintaining a learning factory requires a lot of money and resources, including equipment purchase, technology upgrades, and operating costs(Al Khatib et al., 2023; Christiansen et al., 2021; Damgrave et al., 2023; Enke et al., 2020; Gopal, 2022; Grøn et al., 2020; Hulla et al., 2021; Kleppe et al., 2022; Lindvig & Mathiasen, 2020; Lutters & Damgrave, 2023; Maarof, 2020; M. Maarof & M. Bohari, 2023; M. Maarof & M. Z. Z. Bohari, 2023; Milisavljevic-Syed et al., 2023; Monetti et al., 2023; Nellemann et al., 2022; Nixdorf et al., 2023; Riemann et al., 2021b; Srivastava et al., 2022; Sudhoff et al., 2020; Vijayan & Mork, 2020; Widiaty et al., 2021).	The construction and maintenance of industrial colleges also requires a lot of funds and resources, including facility construction and operating costs. (Gao, 2023; C. Han, 2023; Li, 2024; Lu et al., 2020; Shanna, 2023; Sun & Sun, 2020; Wang, 2023; Wang, 2021; Wu & Cui, 2023; Yuan & Li, 2020; Zhang et al., 2022)。
Technical complexity	Professionals are needed to manage and maintain technologies such as digital production lines and virtual reality environments, and to continuously update technologies and equipment to adapt to industrial development. (Al Khatib et al., 2023; Gopal, 2022; Kleppe et al., 2022; Lutters & Damgrave, 2023; Nixdorf et al., 2023; Riemann et al., 2020; Roll & Ifenthaler, 2020; Scholz et al., 2020; Srivastava et al., 2022; Vijayan & Mork, 2020; Widiaty et al., 2021; Ziarsolo et al., 2023)。	Requires high level of technical support and equipment updates to keep pace with industry development and rapid technological changes (Li, 2024; Li et al., 2022; Shanna, 2023; Wu & Cui, 2023; Yuan & Li, 2020; Zhang et al., 2022)。
Insufficient teaching staff	We need a teaching staff with rich practical experience and teaching ability. The current teaching staff is relatively weak and needs corresponding training. (Al Khatib et al., 2023; Christiansen et al., 2021; Enke et al., 2020; Grøn et al., 2020; Hulla et al., 2021; Kleppe et al., 2022; Lutters & Damgrave, 2023; Maarof, 2020; M. Maarof & M. Bohari, 2023; M. Maarof & M. Z. Z. Bohari, 2023; Milisavljevic-Syed et al., 2023; Monetti et al., 2023; Nellemann et al., 2022; Nixdorf et al., 2023; Riemann et al., 2020; Riemann et al., 2021a, 2021b; Roll & Ifenthaler, 2021; Roll & Ifenthaler, 2020; Srivastava et al., 2022; Sudhoff et al., 2020; Vijayan &	We need "double-qualified" teachers who have both theoretical knowledge and practical experience. Currently, there is a shortage of such teachers, and we need to strengthen the construction of the teaching staff. (Gao, 2023; Li, 2024; Li et al., 2022; Shanna, 2023; Wang, 2023; Wang, 2021; Wu & Cui, 2023; Yuan & Li, 2020)。

Challenges	Learning Factory	Industrial College
	Mork, 2020; Widiaty et al., 2021) ◦	
Difficulty of school-enterprise cooperation	It is necessary to establish a good cooperative relationship with enterprises, but due to problems such as profit distribution and cooperation mechanism, the participation of enterprises is low and the depth of cooperation is insufficient. (Christiansen et al., 2021; Kleppe et al., 2022; Lindvig & Mathiasen, 2020; Lutters & Damgrave, 2023; Maarof, 2020; M. Maarof & M. Bohari, 2023; M. Maarof & M. Z. Z. Bohari, 2023; Milisavljevic-Syed et al., 2023; Nixdorf et al., 2023; Riemann et al., 2020; Riemann et al., 2021b; Widiaty et al., 2021) ◦	The school-enterprise cooperation mechanism is not sound, the enterprise participation is not high, the cooperation depth is insufficient, and it is difficult to form an effective school-enterprise cooperation model (Gao, 2023; Li, 2024; Li et al., 2022; Shanna, 2023; Sun & Sun, 2020; Wang, 2023; Wang et al., 2021; Wang, 2021; Yuan & Li, 2020) ◦
Management and operational complexity	It is necessary to establish effective management systems and organizational models to coordinate and solve the obstacles and challenges in university-enterprise cooperation. (Damgrave et al., 2023; Hvidsten et al., 2022; Lindvig & Mathiasen, 2020; M. Maarof & M. Z. Z. Bohari, 2023; Milisavljevic-Syed et al., 2023; Nixdorf et al., 2023; Riemann et al., 2020; Roll & Ifenthaler, 2020; Widiaty et al., 2021; Witeck & Alves, 2023; Ziarsolo et al., 2023) ◦	The governance structure and operation model need to be improved to solve the problem of imperfect management system. (Li, 2024; Li et al., 2022; Shanna, 2023; Wang et al., 2022; Wang, 2023; Wang, 2021; Wu & Cui, 2023; Yuan & Li, 2020) ◦
Curriculum Development and Reform	The course content and teaching mode need to be continuously updated according to industry needs to enhance students' practical and innovative abilities. (Assad et al., 2020; Damgrave et al., 2023; Enke et al., 2020; Gopal, 2022; Hvidsten et al., 2022; M. Maarof & M. Bohari, 2023; M. Maarof & M. Z. Z. Bohari, 2023; Monetti et al., 2023; Sudhoff et al., 2020; Widiaty et al., 2021) ◦	The curriculum is out of touch with industry needs. The curriculum system needs to be reformed to make the course content more in line with industry needs. (Gao, 2023; Li, 2024; Shanna, 2023; Wang et al., 2021; Yuan & Li, 2020) ◦
Cultural and communication challenges	In international cooperation, it is necessary to overcome cultural differences and language barriers and establish effective communication mechanisms (Scholz et al., 2020; Ziarsolo et al., 2023) ◦	Not mentioned
Time and Team Management	Real learning tasks may take more time to analyze and solve, requiring time	Not mentioned

Challenges	Learning Factory	Industrial College
	management; students need to adapt to teamwork and effective communication (Hvidsten et al., 2022)。	
Other Challenges	Specific issues such as facilities and equipment, student participation, etc. need to be addressed; some learning factories lack attention to sustainable development (Milisavljevic-Syed et al., 2023)。	Need policy support, imperfect management system, lack of top-level design and service capabilities (Li et al., 2022; Sun & Sun, 2020; Wang, 2023; Zhu et al., 2021)。

Conclusion and Suggestion

Through a systematic literature review, this study found that learning factories significantly improved students' practical ability and professional quality by simulating real production environments, while industrial colleges cultivated high-quality application-oriented talents through in-depth school-enterprise cooperation.

However, the study has some limitations: it is based on a literature review of the past five years and fails to fully cover research results over a longer period of time; it lacks field research and interviews, and lacks understanding of actual application situations; there is little research on industrial colleges abroad, and the depth of international comparative analysis is limited.

The research and practice of learning factories are already quite rich, but the industrial college model is still in its early stages of exploration. Future research should combine field research, deeply analyze the implementation effects and challenges of industrial colleges, and explore how to apply successful foreign school-running models to China's vocational education, so as to further improve the quality of education and students' employability.。

Based on the research results, this paper puts forward the following suggestions: strengthen capital investment to ensure the sustainable construction and operation of learning factories and industrial colleges; improve teaching staff through training and introduction of teachers with practical experience; deepen school-enterprise cooperation and establish an effective cooperation mechanism and benefit distribution system; reform the curriculum system, update the course content and teaching mode; improve the management system and establish a sound management and organizational model; focus on sustainable development and promote green education

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