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Research on the Deep Integration Path of Digital Twin Technology and Productive Practical Teaching in Vocational Colleges under the Context of Intelligent Manufacturing Scenarios

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Abstract

China's manufacturing industry has entered a new era of development, transitioning from extensive to high-quality and lean production. The growth rate of the manufacturing sector is gradually shifting from high-speed to medium-high speed, and the production methods are evolving from traditional ones to intelligent manufacturing, collaborative manufacturing, and others. The integration of digitalization and informatization has driven the transformation and upgrading of intelligent manufacturing. Digital twins possess technical characteristics such as virtual-real consistency, virtual-real synchronization, and real-time interaction. Their applications range from simulating reality and digital cities to the industrial field. With the development of lean production and intelligent factories in the manufacturing industry, the interaction relationships and production line scales in the production sites are becoming increasingly complex. The application of digital twin technology throughout the entire life cycle of intelligent factories, including the early construction, mid-term operation, and late prediction phases, demonstrates unique advantages. In the field of vocational education, this paper conducts an in-depth study on the relationship between digital twin technology and the construction of productive training bases. By combining the characteristics of vocational education and teaching, virtual training designed with digital twin technology breaks down the productive training process into units, transforming observational learning into practical learning. It explores a more complete and effective training environment and mode that integrates virtual and real elements in the construction path of vocational education training bases, providing an experience model for vocational education training methods.

Keywords

Digital Twin; Virtual Simulation; Productive Training Base; Construction Path.

1. Introduction

With the continuous development of information technology, it has begun to integrate into human life and various production activities. In the field of intelligent manufacturing, enterprises' production upgrades are also facing digital and intelligent transformations. Especially in recent years, with the breakthroughs in technologies such as artificial intelligence, big data analysis, and industrial internet applications, and their deepening application in the industrial sector.

The manufacturing production mode is gradually shifting from traditional production methods to advanced production methods such as intelligent manufacturing, collaborative manufacturing, and green manufacturing. The rapid upgrading of the intelligent manufacturing industry has changed the requirements for the training specifications of technical and skilled talents. The construction of productive training bases is an important measure to address the differences between the learning content in schools and the technical demands of actual

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production processes. However, vocational colleges face challenges such as high construction costs, difficult scene simulation, and difficult student operation when building productive training bases. In recent years, digital twin technology has developed rapidly in the field of intelligent manufacturing. It not only serves as the data foundation for the digital and intelligent system upgrades in intelligent manufacturing but also provides a solution that combines virtual and real elements for the construction of productive training bases in higher vocational colleges.

2. The Connotation and Architecture of Digital Twin Technology

2.1. Definition of Digital Twin

It is generally believed that the concept of digital twin was proposed by Professor Michael Grieves of the University of Michigan in a PLM (Product Lifecycle Management) speech in 2002, which mentioned the real space, virtual space, and their relationship - that is, the data flow from the real space to the virtual space and the information flow from the virtual space to the real space. In subsequent research, he referred to it as the information mirroring model. Michael Grieves proposed this concept to explain the operating mechanism of PLM, hoping to achieve full lifecycle management through the interaction mapping between virtual models and physical entities.

Although there are still disputes over the definition of digital twin in different application fields today, and the focus of attention is not exactly the same in different application fields, we can see that the concept of digital twin is beginning to show consistency. This includes: the digital twin is a digital model based on physical entities established based on multi-dimensional data information such as features, performance, and working processes; the digital twin and the physical entity have dynamic information interaction throughout the entire lifecycle; they are synchronized in operation, with the physical entity providing data and constantly supplementing or correcting the digital twin; the digital twin can provide guidance and prediction for the physical entity through analysis.

Simply put, the digital twin is a multi-dimensional and high-precision dynamic simulation of the physical entity.

2.2. Architecture of Digital Twin

In 2021, the ISO 23247 series of standards systematically described the definition and framework of digital twin, with a focus on its application in manufacturing.

In ISO 23247, the definition of digital twin is: a digital representation of an observable manufacturing element (OME) that meets requirements, achieving dynamic consistency between the physical element and its digital representation through an appropriate rate of synchronization mechanism. [1]

An observable manufacturing element (OME) refers to an entity in the manufacturing system that has an observable physical existence or operational behavior, including personnel, equipment, materials, processes, facilities, environment, products, and supporting documents, etc. And dynamic consistency (Convergence):

Emphasizes the bidirectional real-time interaction between the physical entity and the digital model, ensuring the precise mapping of the physical state through data collection, synchronization mechanisms, and feedback control.

ISO 23247 provides the framework of digital twin: user layer, digital twin layer, data collection and control layer, and observable manufacturing element layer.

2.3. Application of Digital Twin Systems in the Industrial Field

Digital twin originated in the aerospace field. In the early stage of its development, its application in the industrial field further promoted the development of digital twin technology

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and its application in the civilian field. In the 2010s, industrial giants such as General Electric (GE) and Siemens integrated digital twin technology into their Industry 4.0 strategies, beginning to promote its popularization in intelligent manufacturing.

A complete digital twin system can be applied throughout the entire cycle from research and development, manufacturing and production, operation and maintenance, to update services, running in synchronization with the physical system and continuously updated with data.

2.3.1. Role of Digital Twin Systems in the Research and Development Phase

Traditional equipment design mainly relies on the design experience of designers, using two-dimensional drawings and three-dimensional modeling for design verification and modification. The main application of simulation systems is to test the performance of products in a single dimension. Such a design process often requires repeated attempts when dealing with complex production workshops or complex product designs, and it is also very likely to result in design flaws due to the failure to consider various internal and external related factors. Digital twin technology builds a twin model of the physical entity in the virtual space, allowing designers to simulate various operating conditions of the equipment during the design stage and observe the working status of each component inside the product or equipment. Through multi-dimensional comprehensive analysis, whether it is mechanical or control systems, whether it is the mechanical structure and material properties of individual components or the interrelationships of the entire system, the digital twin system can identify potential design flaws in advance, thereby reducing on-site debugging time, lowering trial operation costs, and enhancing the performance of the equipment.

2.3.2. The Role of Digital Twin Systems in the Production and Maintenance Stages

During the manufacturing process, the virtual system and the physical system operate in parallel, dynamically obtaining comprehensive production data from the product and production line to achieve real-time monitoring. The twin system can also analyze the data through big data analysis and artificial intelligence algorithms, predict and evaluate the performance of the equipment and the quality of the product, promptly detect equipment hazards or abnormal product quality, and issue warnings. It can monitor the status data and energy consumption data from the machines, perform predictive maintenance and repair, prevent downtime, and optimize energy consumption. Digital twins provide a basis for optimizing production scheduling for enterprises, improving production efficiency, and ensuring product quality. At the same time, the realistic three-dimensional effect visually presents the entire production line operation, making it more convenient for enterprises to manage.

2.3.3. Digital Twin Technology Enhances Lean Production Levels

The goal of lean production is to improve efficiency and reduce costs, with the core being the diagnosis of the current situation and continuous improvement. The digital twin system is a high-fidelity and high-simulation system that can completely simulate the entire production elements, including inventory, raw materials, personnel, and all other production elements. Data collection and intelligent analysis further assist enterprises in continuously and dynamically collecting information and analyzing data, establishing and optimizing standardized production processes, and achieving AI-assisted intelligent lean production through digital technology.

2.3.4. Digital Twin Technology Improves Flexible Production Efficiency

For production needs of small batches and multiple batches, a flexible production mode must be adopted. Due to frequent production line adjustments, numerous product parameters, and rapid new product launches, production becomes complex and variable. Such enterprises are among those with greater difficulty in upgrading to intelligent manufacturing automation and

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digitalization. Production line adjustments require production halts for trial runs, but the high-fidelity and high-simulation nature of the digital twin system makes production line adjustments possible. Product production adjustments can be pre-tested on the virtual twin, and the results can be simulated. After adjustments are completed, they can be implemented on the flexible production line, saving production line adjustment time. At the same time, the addition of AI technology can also achieve parameter optimization and dynamic adjustment, improving production and management efficiency.

3. The Feasibility of Integrating Digital Twin Technology and Practical Teaching in Vocational Colleges under the Context of Intelligent Manufacturing Scenarios

3.1. The construction of productive training bases breaks the barriers of talent demand between schools and enterprises

In recent years, the development of intelligent manufacturing has been rapid, with a strong trend towards digitalization. During this process, higher requirements have been put forward for the vocational abilities of intelligent manufacturing talents, such as students' practical hands-on ability, the operation ability of digital systems, and the ability to receive new technologies. However, there are differences between the talent cultivation standards of vocational colleges and the demands of enterprises. The construction of productive training bases is a measure to break the supply and demand barriers of talent specifications. The productive training bases of higher vocational colleges mainly take two forms: school or government investment and the introduction of enterprises into the campus. In the actual operation process, the following drawbacks are presented: the former requires a high investment for schools, and the ideas of training base construction are not in line with the rapid development of enterprises, making it difficult for productive training bases to achieve the expected training goals; the latter often faces contradictions between running talent cultivation and ensuring production efficiency due to enterprises' focus on the production process, making it difficult for students to truly engage in production. Moreover, such training bases, dominated by enterprises, show insufficient technological advancement.

3.2. The integration of digital twin technology enhances the operability of training base construction.

In 2021, the Ministry of Education issued the "Guidelines for the Construction of Demonstration Virtual Simulation Training Bases in Vocational Education", clearly stating that virtual simulation training rooms should focus on solving the "three highs and three difficulties" pain points and difficulties in the training teaching process, namely high investment, high loss, high risk, and difficult implementation, difficult observation, and difficult reproduction. Teaching resources are divided into pure virtual resources that lead with reality, modular resources that assist reality with virtuality, and digital twin resources that combine virtuality and reality. Especially for the last category, it encourages the construction of digital twin resources that can achieve the combination of virtuality and reality. [2]

The essence of the digital twin system is the high-fidelity and dynamic optimization of virtual digital bodies and physical entities. The characteristics of intelligent manufacturing determine that the content of student cultivation includes the integration of technologies such as machinery, control, and digitalization, and it is necessary to cultivate students' practical hands-on ability. Pure virtual systems are difficult to achieve the goal of enhancing students' practical hands-on ability to meet job requirements by simulating the design, operation, and maintenance of factory positions.

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4. The Deep Integration of Digital Twin Technology and Productive Training Bases: Construction Paths

4.1. The depth of digital twin technology integration meets the needs of intelligent manufacturing talent cultivation

From the previous analysis of digital twin technology, we can see that the greatest advantage of digital twin technology is its dynamic high-fidelity simulation, which can provide data basis and possibility for the digital upgrade and full life cycle management of intelligent manufacturing. At the same time, we should also note that in different stages of the full life cycle, the application technologies and software platforms are related but different. For example, when focusing on design and development and layout planning, 3D modeling technology based on multi-physical fields, control logic, and virtual scene factory planning work in synergy; when focusing on system operation and predictive maintenance, data collection and update based on intelligent sensors and industrial networks, as well as artificial intelligence prediction, are very important; for enterprise management and efficiency improvement, Internet of Things technology, artificial intelligence technology, enterprise management, and cloud platforms provide data integration and analysis, and offer suggestions and guidance.

Therefore, for different colleges, the core majors and professional clusters determine the depth of digital twin technology integration and its position in the full life cycle.

4.2. Core modeling technology determines the direction of talent cultivation

Digital twin technology can achieve full life cycle management, and modeling tools are the basis for digital acquisition in intelligent manufacturing. From the layout of the digital field by companies such as General Electric, Siemens, and Dassault in the 2010s to the current application of digital twin technology in the actual construction of Industry 4.0, different modeling products have shown different technical tendencies. For instance, ANSYS focuses on high-precision fields, providing multi-physics coupling simulation tools covering structural mechanics, fluid dynamics, electromagnetic field analysis, etc. It is irreplaceable in complex physical field modeling and high-precision computing; Siemens has a very strong vertical integration capability, spanning from hardware to software systems, from virtual design to physical production and manufacturing execution in a full-process closed loop; Dassault Systèmes supports multi-disciplinary and multi-department collaborative simulation, improving the efficiency of the design stage, and also achieving full life cycle management.

It should be said that different modeling products each have their own characteristics. When building a digital twin system for a productive training base in vocational colleges, it is necessary to deeply analyze the technical advantages of various modeling tools, and select appropriate modeling tools and industrial cloud platforms based on the needs of productive training scenarios and talent cultivation, so as to leverage the advantages of the twin system in practical teaching and make the training more directional in actual teaching practice.

This means that for different majors or major groups, the starting points and focuses are not the same. For example, for mechanical majors, they may be more concerned about the mechanical characteristics of products and have higher requirements for multi-physics coupling and the coordination between mechanical components; for control-related majors such as automation, they are more concerned about various intelligent sensor technologies, industrial network technologies, controller programming structures, and the coordination between mechanical components; for industrial internet technology-related majors, they are more concerned about industrial network data collection, data statistics, and data security; for engineering management and other majors, they focus on system analysis and artificial intelligence prediction for data analysis and optimization management planning. Therefore, when building a digital twin system based on a productive training base in vocational colleges,

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it is also necessary to find a foothold and determine the core content and core technologies to be cultivated. On the other hand, it is not aimed at the training needs of a single major or major group, but to provide benefits for cross-field and cross-disciplinary talent cultivation.

4.3. School-Enterprise Synergy to Build Operation Management and Evaluation Mechanism

The construction of productive training bases and digital twin simulation systems by school and enterprise collaboration, with the training base taking sustainable development as the path and fully demonstrating its teaching, display, and resource sharing functions, requires the joint participation of both parties to establish a good operation mechanism, ensuring the orderly operation of the training base and achieving "resource sharing and advanced technology demonstration". It should be built with the idea of integrating industry and education, design the organizational structure and management department of the training base, and establish a good operation management system and a real-time and specific base operation evaluation system.

In the operation management of the training base, a target evaluation system needs to be established, focusing on the healthy and effective operation of the base. The quality of talent cultivation, teaching staff, innovation ability, and the degree of resource sharing of the base should be the main evaluation criteria, and the evaluation should be conducted from several aspects such as the multi-major and major group co-construction and sharing within the school, industry-academia collaboration, resource sharing, and demonstration and display of the base.

4.4. Reorganization and Construction of Teaching Resources for Blended Virtual and Physical Teaching Projects

In light of the current application status of intelligent manufacturing technology, the teaching in the training base should incorporate new standards, new technologies, and new norms, as well as contents such as modern enterprise management and lean production. The entire production-oriented training system should be restructured into modular units and decomposed into well-functioning systems, establishing positive correlations among different links. From the perspective of enhancing students' practical hands-on abilities, a multi-level curriculum should be developed, including the operation of the entire physical production line, the operation of individual unit modules, and the virtual operation of the twin system. In terms of teaching resource construction, resources should be developed covering several dimensions: virtual simulation design of unit modules, comprehensive control and management of the system, predictive maintenance of the entire line, and modern management based on production data.

At the same time, information and digital technologies should be utilized for production data analysis, fully leveraging the data collection and analysis advantages of digital twin technology to record students' learning and training processes. Through the "data flow", the training process in the training base should be promoted, enabling precise and rapid evaluation of training teaching.

5. Conclusion

Smart manufacturing enterprises are in a high-speed development stage of comprehensive digitalization and networking, with key enterprises in major industries advancing towards intelligence. The deep integration and construction of digital twin systems and productive training bases can narrow the gap in talent cultivation requirements between schools and enterprises, and solve the problems of high investment and difficult teaching in the construction of productive training bases. The application of digital twin technology requires innovation in technical planning during the construction stage, course development during the

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operation stage, and exploration of the co-construction model between industry and education. It transforms observational learning into practical learning, improves the construction of virtual and real integrated course resources and training environments, and enhances the digital application ability of intelligent manufacturing systems for students in higher vocational colleges.

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