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Digital Twins Empower Higher Education

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ABSTRACT

This paper explores the application of digital twin technology in higher education and its enabling effect. Through literature review and case studies, this paper studies the generation, basic concepts, technical frameworks, and application scenarios, e.g., in higher education, of digital twins. The results show that digital twin technology can significantly improve the teaching quality and learning effect and optimize educational resource allocation and management efficiency. This paper also discusses the challenges of digital twin technology and the prospects for future development in higher education. It provides new ideas and practical paths for the digital transformation of higher education.

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1. INTRODUCTION

1.1. Background to the development of digital twin technology

Digital twins are an innovative technology that integrates virtual simulation, data analysis, artificial intelligence, and other technologies and is increasingly used in different fields [1]-[13], including higher education [14]-[29]. The development background of digital twin technology mainly includes the following aspects:

A. Technological progress: With the rapid development of information technology and communication technology, virtual simulation, data analysis, artificial intelligence, and other technologies have made significant progress, providing technical support for realizing digital twin technology.

B. The need for educational reform: The traditional higher education model has many problems, such as single teaching content, rigid learning methods, and difficulty meeting personalized needs. The advent of digital twin technology offers new possibilities for transforming higher education to meet students' needs for customized learning.

C. Social needs: Society has set higher requirements for higher education, hoping that graduates will have more practical, innovative, and problem-solving abilities. Digital twin technology can effectively improve students' practical skills and professionalism by providing a virtual simulation practice environment.

D. EdTech development: The rapid development of the tech sector has also promoted digital twin technology in higher education. Schools and educational institutions are aware of the importance of digital technology and have begun to actively explore the application scenarios of digital twin technology in education.

In summary, the background of digital twin technology empowering higher education results from the combined effect of many factors, including technological progress, the need for educational reform, social needs, and the development of educational technology. Together, these factors have promoted the application and development of digital twin technology in higher education, bringing new opportunities and challenges to the field of education.

1.2. Significance of digital twin technology for higher education

Digital twin technology empowers higher education with multiple implications, including:

A. Improve teaching effectiveness: Digital twin technology can provide a more realistic and vivid learning experience, helping students better understand abstract concepts and complex theories and apply them to real-world problems. Through digital twin technology, educators can create more diverse and three-dimensional teaching scenarios to stimulate students' interest in learning and improve their enthusiasm for learning, thereby improving teaching effectiveness.

B. Personalized learning support: Digital twin technology can provide personalized learning support and assistance according to students' learning characteristics and needs to meet the learning needs of different students. This will help educators pay attention to each student's differences, tailor learning paths and resources, improve learning efficiency, and stimulate potential.

C. Improve practical skills: Digital twin technology can provide students with a virtual simulation practice environment to help them explore and develop skills in a safe and controllable scenario. This not only facilitates students' practice in a more realistic environment but also avoids safety hazards and the waste of resources caused by limited practice environments.

D. Promote innovation in teaching and learning models: Digital twin technology has brought new teaching models and methodologies to higher education, such as scenario-based learning and collaborative learning across time and space. This helps break down traditional teaching models' rules and regulations, promote the diversification and personalization of teaching content and forms, and stimulate students' creativity and innovative thinking.

E. Nurturing future talent: Digital twin technology empowers higher education to develop future talent with practical, innovative, and problem-solving skills. These abilities are essential for adapting to social development and scientific and technological progress in the information age and are also one of the fundamental goals of higher education.

To sum up, the significance of digital twin technology empowering higher education is to improve teaching effectiveness, realize personalized learning support, cultivate practical ability, promote teaching mode innovation, and lay a solid foundation for nurturing future talents. This is conducive to higher education, better meeting society's needs, and talent training.

1.3. Purpose of the study

In recent years, higher education has faced several challenges, such as resource constraints, diversification of student needs, and uncertainty in the teaching and learning environment. To address these issues, educators must better understand students' learning behaviors and teaching outcomes to make more informed decisions. Digital twin technology offers a new solution that simulates and analyzes students' learning processes and teaching environments in real-time by creating virtual digital models. This study aims to explore the application of digital twin technology in higher education and explore its potential impact on teaching and learning, which includes:

A. Improve teaching effectiveness: Digital twin technology can provide students with a more realistic and vivid learning experience, enhance their learning interest and participation, and improve teaching effectiveness. One study aims to explore how digital twin technology can be used to optimize curriculum, design instructional content, and deliver instructional activities to enhance student learning performance and learning experience.

B. Personalized learning support: Digital twin technology can provide personalized learning support and assistance according to students' learning characteristics and needs. One research aim is to explore the potential of digital twin technology in personalized learning, design and develop corresponding intelligent systems and tools, and provide students with customized learning paths and resources to help them achieve their learning goals.

C. Improve practical skills: Digital twin technology can provide students with a virtual simulation practice environment to help them explore and develop skills in a safe and controllable scenario. One research aim is to explore how to use digital twin technology to design and create realistic virtual simulation practice environments and how to effectively guide students to practice and accumulate experience in the teaching process.

D. Promote innovation in teaching and learning models: Digital twin technology has brought new teaching models and methodologies to higher education, such as scenario-based learning and collaborative learning across time and space. One of the purposes of this research is to explore the influence and promotion of digital twin technology on teaching models and promote the innovation and transformation of education and teaching models to meet the educational needs of the information age.

In general, the research purpose of digital twin technology empowering higher education is to use advanced technical means and methods to optimize the teaching process, improve the teaching effect, personalize learning support, cultivate practical ability, and promote the innovation and improvement of education and teaching mode in the context of the current educational reform, better to meet the needs of social development and talent training.

1.4. Research methods

This study uses the literature review method to identify and analyze the application of existing digital twin technology in higher education. By collecting and synthesizing relevant research papers, reports, and case studies, we summarized a range of application scenarios for digital twin technology and evaluated their effects and challenges.

2. DIGITAL TWIN TECHNOLOGY AND ITS APPLICATION IN HIGHER EDUCATION

2.1. The emergence of the concept of digital twins

In 2003, Michael Grieves of the University of Michigan proposed the "mirror space model" concept in product life cycle management, the prototype of the "digital twin." Its primary connotation is a three-dimensional model that includes the connection of data and information between physical entities, virtual entities, and virtual and natural entities. In 2012, NASA officially proposed the "Digital Twin" concept and applied it to the design, testing, and operation of spacecraft and aircraft, laying a theoretical foundation and practical experience for the later development of digital twin technology.

The emergence of digital twin technology is closely related to the development of science and technology, the improvement of data processing capabilities, and the growing demand for complex system management.

A. Technological development: With the continuous development of computer technology, sensor technology, cloud computing, and big data technology, people's ability to obtain and process data has been dramatically improved. This opens up the possibility of building digital models and real-time monitoring of complex systems.

B. Interdisciplinary integration: The generation of digital twin technology also benefits from integrating multiple disciplines. Knowledge and technology in computer science, engineering, physics, mathematics, cybernetics, and other fields are integrated, providing theoretical and technical support for developing digital twin technology.

C. Growing demand for managing complex systems: In modern society, the size and complexity of complex systems (e.g., industrial production systems, urban infrastructure, transportation systems, etc.) are increasing, making it more challenging to manage them. Digital twin technology was created to understand and manage these complex systems better, improving operational efficiency and safety.

Overall, digital twin technology combines digital technologies, interdisciplinary convergence, and the growing demand for complex systems management. It provides new ideas and methods for managing, operating, and optimizing various entities and systems and has become an important development direction in today's industrial and technological fields.

2.2. Basic concepts of digital twin technology

The concept of digital twin technology is derived from the human need to manage and optimize complex systems. Through digital twin technology, various physical entities' characteristics, behaviors, and states can be digitized and synchronized with the actual entity in real-time to form a "twin" relationship. Such digital twins can help people better

understand and manage physical entities, identify problems before they occur, take preventive measures, and even conduct virtual experiments and optimize designs.

Digital twin technology typically includes the following key components:

A. Data collection and integration: Various sensors, monitoring equipment, and information systems obtain data on physical entities, such as temperature, pressure, vibration, location, etc.

B. Model construction and simulation: Based on the collected data, establish a digital model of the physical entity, including structure, behavior, association, etc., and simulate the running state of the entity through simulation technology.

C. Real-time monitoring and analysis: Synchronize the digital model with the actual entity in real-time, monitor the physical entity's state changes, analyze the data, and identify anomalies.

D. Prediction and optimization: Based on the digital model's analysis results, predict the physical entity's future state and take corresponding optimization measures to achieve more efficient and reliable operation.

The application of digital twin technology involves various aspects such as manufacturing, industrial automation, smart cities, logistics and supply chain management, and energy. Digital twin technology can realize intelligent monitoring, predictive maintenance, virtual simulation optimization, and other functions, providing strong support for managing, operating, and optimizing various entities and systems.

2.3. Characteristics of digital twin technology

Digital twin technology has the following notable features:

A. Real-time: Digital twin technology can realize real-time monitoring and feedback on physical entities or systems. The digital twin can be updated promptly to reflect the physical entity's latest status and changes to support real-time decision-making by connecting to real-time data sources such as sensors and monitoring devices.

B. Transtemporal and temporal nature: Digital twin technology enables the monitoring and analyzing of physical entities or systems that are no longer limited by geographical location and time constraints. Whether remote monitoring or back-to-back analysis of historical data, it can be realized through digital twin technology, which allows cross-regional and cross-time management and analysis.

C. Virtual simulation: Through digital twin technology, the physical entity or system can be simulated virtually to simulate the operating state and performance under different working conditions. This provides an essential reference for design optimization, risk assessment, and other work.

D. Predictive maintenance: Based on digital twin models and data analysis, it can predict the future state of physical entities or systems and provide corresponding maintenance suggestions and optimization plans to help identify problems in advance and take measures to avoid equipment failures and downtime losses.

E. Diverse applications: Digital twin technology can be applied to many fields, including industrial manufacturing, smart cities, energy management, transportation,

healthcare, etc. Its flexibility and versatility make it an essential support for various industries' digital transformation and intelligent development.

In general, digital twin technology has the characteristics of real-time, cross-temporal and space, virtual simulation, predictive maintenance, and diversified applications, which provide new ideas and methods for the management, operation, and design of entities and systems and has become an important development direction in today's industrial and technological fields.

2.4. Technical framework for digital twins

The technical framework of a digital twin typically includes the following key components:

A. Data acquisition and sensor network: This is the foundation of digital twin technology, which collects data from physical entities or systems in real-time through various sensors and monitoring devices, such as temperature, pressure, humidity, vibration, and other parameters. The data updates the digital twin to reflect the physical entity's real-time state.

B. Digital modeling: Convert the collected data into a digital model, including physical structure, component relationships, operating behaviors, performance parameters, and other information. This digital model can be a physical model based on physical laws or a data-driven statistical model.

C. Real-time synchronization and updating: Ensure real-time synchronization between the digital twin and the actual physical entity and keep the digital model able to reflect the physical entity's latest status and changes through real-time data update and transmission. This is usually achieved with the help of cloud, edge, and other technologies.

D. Data analysis and intelligent algorithms: Use data science and machine learning techniques to analyze and process the collected data, extract useful information, and discover potential patterns. Intelligent algorithms can also realize real-time monitoring, anomaly detection, predictive analysis, and other data functions.

E. Virtual simulation and optimization: Virtual simulation based on a digital twin model simulates the operating state and performance under different working conditions, helping to optimize design, improve operation mode, and improve efficiency. With virtual simulation, the impact of various scenarios can be evaluated, and the optimal solution can be found.

F. Visualization and decision support: Visualize the digital twin's results in an intuitive graphical interface to help users better understand the state and performance of physical entities. Users can make more accurate and timely decisions and optimize management and maintenance strategies through visualization.

In summary, the technical framework of digital twins mainly includes data acquisition and sensor networks, digital modeling, real-time synchronization and update, data analysis, intelligent algorithms, virtual simulation and optimization, visualization, and decision support. Together, these components form a complete framework for digital twin technology, providing comprehensive support for the management, operation, and design of entities and systems.

2.5. Application scenarios of digital twin technology

Digital twin technology has a wide range of application scenarios in various fields, including:

A. Industrial manufacturing: Digital twin technology can be applied to monitoring and maintaining factory equipment through real-time data collection and analysis, predicting equipment failures, and providing preventive maintenance recommendations. In addition, the digital twin enables virtual simulation of the production process, optimizing the production line layout, process design, and material flow and improving production efficiency and quality.

B. Smart city: Digital twin technology can monitor and manage urban infrastructure, such as intelligent transportation systems, water supply networks, power networks, etc. Through the digital twin model, real-time monitoring and prediction of urban facilities can be realized, urban operation and resource utilization can be optimized, and the intelligent level of urban operation can be improved.

C. Energy management: Digital twin technology can be applied to the monitoring and optimizing of energy equipment, such as wind farms and solar power stations. Through the digital twin model, real-time condition monitoring and predictive analysis of energy equipment can be realized, and the operation mode of equipment can be optimized, improving energy efficiency.

D. Healthcare: Digital twin technology can be applied to the monitoring and maintenance of medical equipment; through the digital twin model, real-time monitoring and predictive analysis of medical equipment can be realized, the reliability and safety of medical equipment can be improved, and the quality of medical services can be ensured.

E. Internet of Things (IoT) devices: Digital twin technology can be applied to monitor and manage IoT devices. Through digital twin models, real-time status monitoring and remote control of IoT devices can be realized, improving their intelligence level and service quality.

F. Architectural design and operation: Digital twin technology can be applied to building design and operation management, and the monitoring and optimization of energy utilization, indoor environment, and equipment operation can be realized through digital twin models, improving building comfort and energy savings.

In summary, digital twin technology has a wide range of application scenarios in industrial manufacturing, smart cities, energy management, healthcare, IoT devices, building design and operation, and other fields, providing important support for various industries' digital transformation and intelligent development.

2.6. Application of digital twin technology in higher education

2.6.1. Scope of application

The application of digital twin technology in higher education includes, but is not limited to, the following:

A. Personalized customization of teaching content:

Digital twin technology can monitor and analyze students' learning and needs in real-time, helping teachers to personalize teaching content. This means that the teaching content

can be adjusted according to each student's learning ability, interests, and learning style to meet the learning needs of different students better and improve the teaching effect.

B. Virtual Simulation Experiments:

Digital twin technology can build a virtual simulation experiment environment to give students a richer and more intuitive experimental experience. This virtual experimental environment can make up for the shortcomings of traditional experimental facilities and, at the same time, improve the effect of experimental teaching so that students can carry out experimental operations in a safe and controllable environment and deepen their understanding of experimental principles.

C. Learning process monitoring and feedback:

Through digital twin technology, students' learning process and performance can be monitored in real-time, providing data support for teachers. This way, teachers can keep abreast of students' learning, identify problems, adjust teaching strategies promptly, and provide personalized learning guidance and feedback. This personalized monitoring and feedback mechanism can help students better understand knowledge and improve learning outcomes.

D. Online Collaboration & Interaction:

Digital twin technology can also support online collaboration and interaction, allowing students to work on team projects in a virtual environment to solve problems and exchange ideas. This online collaboration platform can promote student interaction and cooperation and develop team spirit and communication skills.

In general, the application of digital twin technology in higher education mainly focuses on personalized teaching content, virtual simulation experiments, learning process monitoring and feedback, and online collaboration and interaction. These applications enrich teaching methods, improve teaching effectiveness, and promote teaching innovation and student participation, bringing new development opportunities for higher education.

2.6.2. Application status at home and abroad

In the United States, some universities and research institutes are beginning to explore the application of digital twin technology in higher education. For example, some engineering majors use digital twin technology to conduct virtual simulation experiments to give students a richer hands-on experience. Some European higher education institutions have also experimented with applying digital twin technology, mainly focusing on personalized teaching content, learning process monitoring and feedback, etc. Some schools use digital twin technology to provide online collaboration and interaction platforms to facilitate student collaboration and communication. Tsinghua University is a leader in education informatization and has begun to try to introduce digital twin technology into higher education. They use digital twin technology to build a virtual simulation experiment environment to provide students with a more intuitive experimental experience. Shanghai Jiao Tong University is also exploring the application of digital twin technology in digital transformation in higher education. They are committed to personalizing the teaching content and using digital twin technology to differentiate the learning needs of different students and improve the teaching effect. Peking University is also actively promoting the

development of digital education and the application of digital twin technology at the university is mainly focused on learning process monitoring and feedback. They use digital twin technology to monitor student learning in real-time and provide teachers with data to help improve the quality of teaching.

Generally, higher education institutions at home and abroad actively explore the application of digital twin technology in education. This involves personalized customization of teaching content, virtual simulation experiments, learning process monitoring and feedback, and other aspects. As technology evolves and improves, digital twin technology is expected to bring more innovation and change to higher education.

3. FINDINGS

The study found that digital twin technology has broad potential applications in higher education. First, digital twin technology can optimize the teaching environment and equipment and improve students' learning interest and practical ability through virtual simulation and simulation experiments. Second, digital twin technology can provide personalized learning plans and resources that can be adjusted in real time according to students' learning habits and abilities to improve learning outcomes. In addition, digital twin technology can also be used for intelligent tutoring and assessment, which can help students better grasp knowledge by analyzing their learning data and providing real-time feedback and guidance. Specific benefits include:

A. Personalized Education:

Digital twin technology can customize teaching content according to each student's learning ability, interests, and learning style, helping teachers better meet the learning needs of different students and improve teaching effectiveness.

B. Virtual Simulation Experiment:

Digital twin technology can build a virtual simulation experiment environment to give students a richer and more intuitive experimental experience. This virtual experimental environment can make up for the shortcomings of traditional experimental facilities and, at the same time, improve the effect of experimental teaching so that students can carry out experimental operations in a safe and controllable environment and deepen their understanding of experimental principles.

C. Learning Process Monitoring & Feedback:

Through digital twin technology, students' learning process and performance can be monitored in real-time, providing data support for teachers. This way, teachers can keep abreast of students' learning, identify problems, adjust teaching strategies promptly, and provide personalized learning guidance and feedback. This personalized monitoring and feedback mechanism can help students better understand knowledge and improve learning outcomes.

D. Resource Sharing & Online Collaboration:

Digital twin technology can support online resource sharing and collaborative learning. It allows students to work on team projects in a virtual environment to solve problems and exchange ideas. This online collaboration platform can promote student interaction and cooperation and develop team spirit and communication skills.

E. Teaching Efficiency Improvement:

Digital twin technology can improve teaching efficiency by reducing the cost of laboratory equipment through virtual experiments while saving time and labor costs. In addition, the digital learning and teaching process can also improve the efficiency and accuracy of information transfer.

In summary, the advantages of digital twin technology in higher education are mainly reflected in personalized education, virtual experiments, learning process monitoring and feedback, resource sharing and online collaboration, and teaching efficiency improvement. These advantages help to realize the effective integration and sharing of teaching resources, improve teaching efficiency, reduce teaching costs, and improve the learning experience. It helps to provide teachers with more teaching tools and methods, promote teaching innovation and practice, and stimulate students' interest and potential in learning. It helps to give a more intuitive and vivid learning experience, enhance students' understanding and memory of knowledge, and stimulate their enthusiasm and initiative in learning.

4. DISCUSSION

The findings of this study show that digital twin technology offers new opportunities and possibilities for higher education. However, the application of digital twin technology also faces challenges, such as technical costs, data security, and privacy protection. Therefore, educational institutions and researchers need to work together to address these issues and further explore the application of digital twin technology in higher education. The specific challenges include:

A. Technology Maturity:

Digital twin technology must involve big data processing, virtual simulation, artificial intelligence, and other fields. The application of these technologies in higher education is still in the exploration stage. The technology's immaturity and instability can lead to problems such as unstable system operation, poor performance, or security risks.

B. Input Costs:

Implementing digital twin technology requires a significant investment of human, material, and financial resources, including purchasing and maintaining technical equipment and software platforms, training, and adapting teachers and students to new technologies. These investments could make it challenging for universities to transform digital education.

C. Teacher Training:

Exceptionally experienced teachers may find training to apply digital twin technology challenging. They need to take the time to learn and become familiar with new teaching tools and platforms and constantly update their teaching concepts and methods, which requires support and training programs from educational institutions.

D. Content Richness:

Personalized teaching requires more prosperous and diverse teaching content, but digital twin technology still has limited coverage. Therefore, it is a challenge to ensure that the teaching content provided by digital twin technology can meet the needs of various students.

E. Privacy & Security:

Privacy and security issues such as students' and teachers' personal information and learning data have attracted much attention in digital education. The application of digital twin technology requires a sound privacy protection mechanism to prevent data leakage and abuse and ensure educational information security.

F. Technology Update & Maintenance:

The rapid upgrading of digital twin technology may require universities to continuously follow up on new technologies and upgrade and maintain systems, which puts higher requirements on university technical support teams.

In summary, digital twin technology faces challenges in higher education, such as technology maturity, input costs, teacher training, content richness, privacy and security, and technology update and maintenance. Overcoming these challenges requires universities and institutions to work together to strengthen technology research and innovation and provide the necessary support and training to ensure the smooth progress of digital education.

5. FUTURE PROSPECTS

Digital twin technology has a broad future outlook in higher education and can lead to significant developments in the following areas:

A. Personalized Learning Experience:

Digital twin technology can be customized to personalize learning paths and content based on each student's learning abilities, interests, and learning style. By monitoring students' learning in real time, the system can continuously optimize teaching resources and provide a learning experience that aligns more with students' needs.

B. Virtual Simulation Practice:

Using digital twin technology, higher education can provide a more realistic and immersive virtual simulation practice environment to help students practice in safe conditions and improve their practical skills and problem-solving skills.

C. Collaborative Learning Across Time and Space:

Digital twin technology can break the limitations of time and space and realize cross-time and space collaborative learning between students and teachers and students and students. Students can study, discuss, and collaborate online anytime and anywhere, promoting academic communication and teamwork skills.

D. Data-Driven Decision-Making:

By collecting and analyzing large amounts of student data through digital twin technology, colleges and universities can better understand students' learning and needs, optimize curriculum design, teaching methods, and assessment methods, enable data-driven teaching decisions, and improve teaching quality and effectiveness.

E. Teaching Resource Sharing:

Digital twin technology can realize the digitalization, sharing, and openness of teaching resources, and different universities can share high-quality teaching resources to improve the overall teaching level and international competitiveness.

F. Lifelong Learning Support:

With society's rapid development and knowledge upgrading, digital twin technology can support lifelong learning, help individuals continue to learn, grow, and adapt to new career needs, and promote the development of vocational education and skills training.

With digital twin technology's continuous development and improvement, its application in higher education will be further promoted and deepened. This will bring a more intelligent, flexible and high-quality development path to higher education and promote the reform and improvement of education and teaching modes. We expect digital twin technology to bring more innovation and change to higher education and help cultivate more innovative and practical talents.

6. CONCLUSION

As an innovative means of educational technology, digital twin technology has brought unprecedented development opportunities and challenges to higher education. Through the empowerment of digital twin technology, higher education can achieve the goals of personalized teaching, virtual learning, cooperation and interaction, intelligent decision-making, and resource sharing. Integrating this kind of technological capability will profoundly change the traditional teaching model and promote the development of the education field in the direction of more intelligent, flexible and efficient.

Powered by digital twin technology, higher education will usher in a comprehensive transformation:

A. Personalized Learning: Students can customize their learning paths according to their needs and interests to achieve personalized learning and improve learning effectiveness and enthusiasm.

B. Virtual Simulation Practice: Students can practice in a virtual environment, enhancing their hands-on ability and reducing practical risks and costs.

C. Global Education: Digital twin technology facilitates cross-border education cooperation and promotes the sharing and exchanging of global educational resources.

D. Data-driven decision-making: Education managers can use data analysis to optimize the allocation of teaching resources, curriculum and evaluation methods and improve the quality and effectiveness of teaching.

E. Lifelong Learning Support: Digital twin technology supports lifelong learning, helping individuals continuously learn and adapt to professional development demands.

In general, digital twin technology offers a new solution for higher education to improve the quality of teaching and student learning. It is expected to drive innovation and development in education by optimizing teaching environments and equipment, providing personalized learning plans and resources, and intelligent tutoring and assessment. However, applying digital twin technology still needs to overcome some challenges and requires further research and practice.

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