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Exploration and Practice of Virtual Simulation Experiment Teaching for Cross-Grades Talent Cultivation from the Perspective of Smart Education

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Abstract: Under the background of the national digital transformation of education and teaching in China, and regarding the demands of cross-grades integrated talent cultivation, the National Virtual Simulation Experimental Teaching Center for Equipment Manufacturing in the University of Shanghai for Science and Technology (USST), relying on virtual simulation experiments, has been continuously carrying out virtual simulation experimental teaching reforms for cross-grades cultivation. These reforms include the "integration of primary, secondary, and higher education" and the "integration of undergraduate and postgraduate education" empowered by wisdom education, breaking through disciplinary boundaries and educational - stage barriers. By creating intelligent and boundaryless virtual simulation experimental teaching scenarios, expanding digital virtual simulation experimental teaching resources, and innovating the cross-grades virtual simulation experimental teaching system, the center provides students with more flexible practical spaces and richer learning resources. This can meet students' individualized demands and academic interests better, and offers significant support for cultivating high - quality talents with innovative spirits and practical abilities.

1. Introduction

In January 2025, the Outline of the Plan for Building a Strong Education Country (2024 - 2035) has been issued, explicitly proposing to "open up new development paths and shape new development advantages through educational digitalization, implement the national educational digitalization strategy, and promote educational transformation with the assistance of artificial intelligence[1]. Currently, advanced information technologies represented by the Internet, big data, artificial intelligence, virtual reality, augmented reality, and blockchain technology are developing at a rapid pace. "Smart education," which integrates these technologies with teaching and learning, has become an irresistible trend and an important measure to promote the high - quality development of the national educational digital transformation[2,3]. Empowering virtual simulation experimental teaching with smart education can significantly enhance the in - depth integration of

teaching and learning in terms of time, space, and knowledge. By constructing digital virtual scenarios, it effectively expands and extends traditional physical experimental teaching, achieving the goal of "expanding the virtual with the real, assisting the real with the virtual, and strengthening the real with the virtual" [4,5]. Through immersive experiences and intelligent interactions, students transform knowledge into competencies, elevate theories into intellectual ethos, and enhance their innovative consciousness, practical skills, and social responsibility.

Meanwhile, to ensure the continuity of talent cultivation and personalized development and optimize the vertical connection and progressive development of educational resources, an innovative model of cross-grades education has been proposed. Through the collaborative cooperation of the "primary - secondary - tertiary education integration" across primary, secondary, and university stages and the "undergraduate - postgraduate education integration" between undergraduate and postgraduate stages, students' knowledge horizons in different disciplines can be broadened, and their innovative inspiration can be stimulated, thus promoting their all - around development [6, 7]. This paper focuses on the national information - based education strategy and the development needs of cross-grades education, conducts research and exploration on virtual simulation experimental teaching for cross-grades talents from a smart perspective, aiming to cultivate compound talents with interdisciplinary thinking, innovative practical abilities, and comprehensive qualities for the country and society.

2. Practical Measures for Cross-Stage Virtual Simulation Experiment Teaching from a Smart Perspective

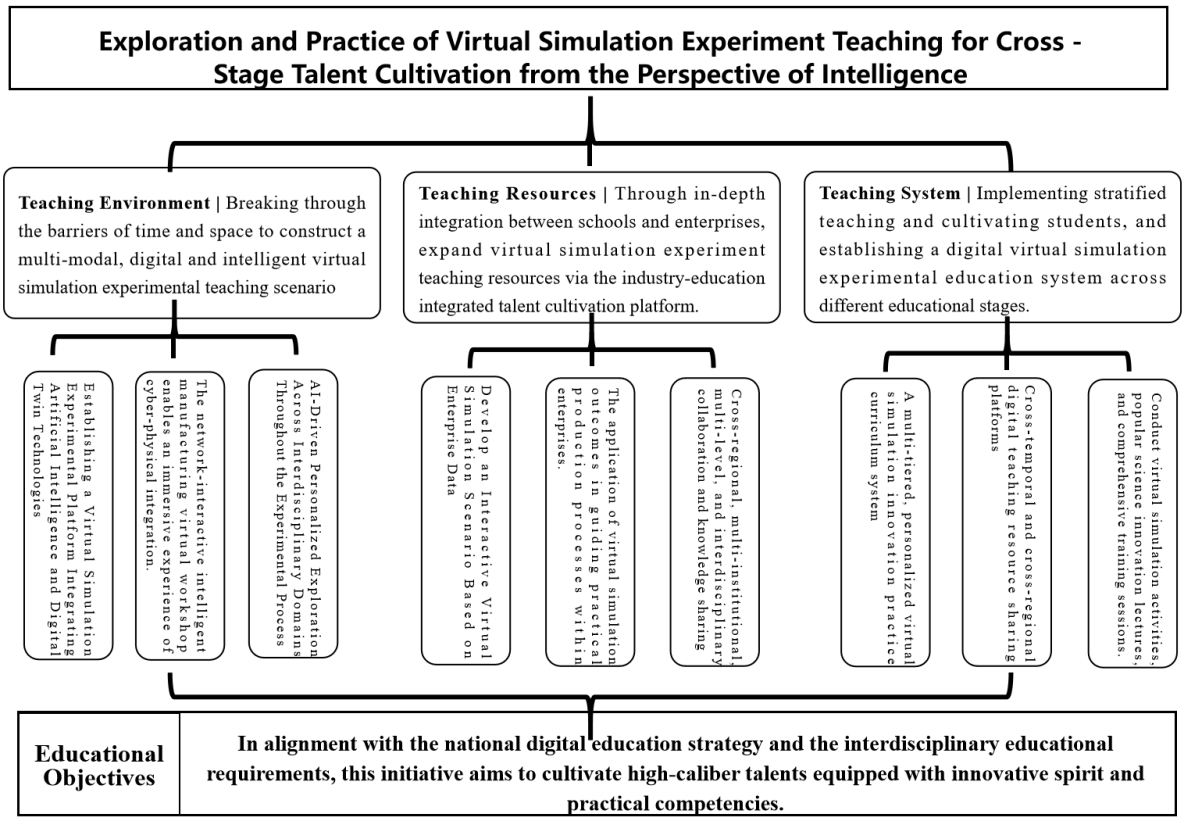

Figure 1: Cross-Grade Virtual Simulation Experiment Teaching Practice System and Strategies from the Perspective of Smart Education.

The National Virtual Simulation Experimental Teaching Center for Equipment Manufacturing at

the University of Shanghai for Science and Technology has long been dedicated to teaching and research in the interdisciplinary fields of high - end equipment, artificial intelligence, and virtual simulation technologies. In response to the national strategic initiative for educational digitalization and the development needs of cross-grades talent cultivation, it has carried out intelligent and personalized cross-grades virtual simulation experimental teaching reforms and innovations across the entire process from "teaching environment - teaching resources - teaching system". It creates a borderless teaching space using artificial intelligence technology, expands virtualized teaching resources through industry - education integration, and constructs a cross-grades virtual simulation education system based on hierarchical cultivation. The specific teaching practice measures and system are shown in Figure 1.

2.1. Breaking through the barriers of time and space to construct a multi-modal, digital and intelligent virtual simulation experimental teaching scenario

To optimize the resource allocation in smart education, the virtual simulation experiment environment is required to possess advantages in aspects such as a vast amount of rich resources, a freely open environment, intelligent adaptive recommendation, and data analysis and processing, so as to expand the interactive experience of students during experimental and practical processes. By integrating artificial intelligence technology into the virtual simulation experiment process, it is possible to achieve multi - participation, co - construction, and sharing of digital educational resources, create immersive teaching scenarios, and shape a new educational environment that makes students feel as if they are on the scene, thus realizing the goal of "everyone can learn, everywhere can be a learning place, and every moment can be a learning time" and completing the technological upgrade of the existing virtual simulation teaching platforms and teaching environments.

Combining the characteristics and disciplinary features of the University of Shanghai for Science and Technology, focusing on the key technologies in the high - end equipment manufacturing process in fields such as aerospace, marine ports, vehicle engineering, and electronic equipment, an "AI + digital twin" equipment manufacturing virtual simulation experiment teaching platform is constructed. By integrating immersive hardware such as AR/VR, mobile terminals, PCs, brain - computer interfaces, and wearable devices, as well as technologies such as static scanning, real - time rendering, and development engines, a multi - modal sensory interactive experience environment featuring voice, touch, voice control, movement, eye movement, virtual reality input, and intelligent interaction is created to build a boundary - less learning space. A network - interactive intelligent manufacturing virtual workshop with software and hardware environments including production lines, CNC machining centers, robots, and AGV and other automation systems is established. Relying on carriers such as virtual manufacturing units, workshops, factories, and supply chains, and in combination with the physical control system of the laboratory, a platform is built to control the operation of virtual prototypes, providing students of different school ages with a variety of rich virtual - real integrated practical experiences. The personalized learning characteristics of students at different educational stages are explored. With the help of technologies such as three - dimensional digital space positioning, computer vision, and collision detection, integration is carried out according to the process of "basic simulation platform construction - AI module integration - multi - terminal access cloud platform construction". From experiment design to evaluation, everything is integrated with AI, providing students with more platforms and opportunities for exploration and innovation, and promoting personalized learning and active exploration empowered by digital and intelligent technologies.

2.2. Through in-depth integration between schools and enterprises, expand virtual simulation experiment teaching resources via the industry-education integrated talent cultivation platform

In collaboration with leading enterprises in the industry, such as Shanghai Machine Tool Works Co., Ltd., Shanghai Electric Central Research Institute, and Zhenhua Heavy Industries Co., Ltd., relying on the in - depth integration of schools and enterprises, the teaching model will be optimized, teaching resources will be integrated, and a multi - functional talent cultivation platform jointly built and managed by schools and enterprises with strong radiation effects and social service functions will be established.

In response to the national strategy of strengthening the country through talent and the development needs of Shanghai to build a global science and technology innovation center, taking the manufacturing of core components of high - end equipment such as C919, port cranes, new energy vehicles, and semiconductor processing equipment as the teaching objects, the key technologies of high - end equipment manufacturing, including ultra - large multi - axis compound machine tools, high - speed and high - precision manufacturing equipment, and giant heavy - duty manufacturing equipment, will be systematically sorted out. Combined with virtual reality technology, large - scale and multi - source heterogeneous interactive virtual simulation scenario cases will be constructed to form a complete and systematic virtual simulation teaching case library for high - end equipment manufacturing key technologies that runs through multiple educational stages, and the high - quality resources of enterprises and industries will be used to expand virtual simulation education and teaching resources. At the same time, the talent cultivation process of virtual simulation education and teaching will be closely linked with the application needs of enterprises. Enterprises can directly apply excellent virtual simulation teaching results to guide actual production, thereby enhancing the enthusiasm and initiative of enterprises to participate in the construction of virtual simulation platforms in universities. Meanwhile, enterprise experts will participate in educational and teaching guidance to help cultivate high - level professional and technical talents with virtual simulation capabilities and the ability to solve complex engineering problems.

In addition, in line with the concept of "based on service and collaborative education", regular seminars and exchanges will be carried out with relevant enterprises and institutions. The industry influence will be enhanced by organizing various virtual simulation technology exchange activities. By joining national or provincial-ministerial R & D public platforms, the number of virtual simulation cases will be expanded through the sharing of large-scale instruments and equipment, and experimental teaching resources will be managed efficiently. By organizing or guiding online-offline hybrid virtual reality interactive experience activities on and off campus, in Shanghai and even in the Yangtze River Delta region, the sharing of virtual simulation teaching resources will be realized to meet the virtual simulation experimental teaching needs of multiple regions, schools, educational stages, and disciplines. Ultimately, the results will be promoted and radiated to serve national and social development.

2.3. Implementing stratified teaching and cultivating students, and establishing a digital virtual simulation experimental education system across different educational stages

To enhance the social service function of virtual simulation teaching models and establish a cross-stage integrated teaching approach, virtual simulation experimental teaching resources are modularly designed and hierarchically reconstructed. Based on the academic and psychological characteristics of students at different educational stages, a progressive and spiraling virtual simulation experimental teaching system is constructed to ensure effective articulation of virtual

simulation teaching across various educational levels. For primary and secondary school students as well as junior undergraduates, science popularization and innovation-oriented teaching focused on cultivating innovative capabilities is implemented. For senior undergraduates and graduate students, advanced heuristic teaching centered on developing engineering thinking skills is conducted, fostering students' abilities from basic skill training to solving complex engineering problems, thereby multi-dimensionally improving the quality of talent cultivation through integrated teaching.

Leveraging the advantages of network-interactive virtual simulation experiments, which are not constrained by time, location, or format, a co-construction and sharing system of virtual simulation educational resources integrating multidisciplinary content is established. Based on the cognitive levels and thinking characteristics of students across different age groups (including undergraduates, graduates, and primary/secondary students), multi-level and personalized virtual simulation innovation practice courses are developed. The complex virtual manufacturing intelligent workshop is decomposed into multiple modular intelligent processing units, designing a "sequentially connected, spiraling upward, and arbitrarily combinable" course teaching system. Students can autonomously select experimental content and conduct virtual simulation experiments according to their interests, optimizing and forming a virtual simulation innovation education curriculum system that meets the needs of students of different ages and cognitive levels. By decomposing and integrating complex actions and processes in equipment manufacturing, a series of knowledge points suitable for students at different educational stages are created, establishing cross-temporal and cross-regional digital teaching shared resources, thereby breaking the course isolation effect among different educational stages. Regular virtual simulation experience activities and science popularization innovation lectures are conducted in primary/secondary schools and social organizations, with the publication of science popularization innovation books and related multimedia products. Interdisciplinary and comprehensive practical ability training is provided for undergraduates and graduates, achieving effective articulation of "primary-secondary-undergraduate-graduate" integrated talent cultivation and implementing social service functions.

3. The pedagogical outcomes are remarkably significant

3.1. The outcomes of cross-disciplinary virtual simulation-based teaching have yielded substantial achievements

The expansion and application of virtual simulation experimental teaching resources empowered by artificial intelligence have facilitated the organization of cross-regional science and technology exchange activities such as "Shanghai-Qinghai Research Study," which have benefited students across five provinces. These initiatives have garnered six feature reports on CCTV's Science and Education Channel and over 40 feature articles in provincial and municipal media outlets. The achievements were exhibited twice at the Shanghai International Youth Science and Technology Expo. The team has been honored with the title of "Advanced Collective in China's Machinery Industry Education" and has been recognized as a Shanghai Municipal Science Education Base, Shanghai Student (Youth) Science and Innovation Education Base, Shanghai Municipal Student Social Practice Base, and Shanghai Youth Innovation Laboratory, among other provincial and ministerial-level educational platforms. Building on the accumulated experience in cross-disciplinary talent cultivation through the "Undergraduate-Graduate Integration" model, the team has secured two "Undergraduate-Graduate Integration" course projects and industry-university cooperative graduate course projects at the University of Shanghai for Science and Technology. Collaborations include the establishment of the University of Shanghai for Science and Technology's Excellence in Engineering Industry-University Co-construction Frontier Course with the Central Research Institute of Shanghai Electric Group Co., Ltd., and the "Industry-Education

Integration Community" construction project with Shanghai Bearing Technology Research Institute Co., Ltd.

3.2. The outcomes have achieved a significant exemplary and radiating impact

In collaboration with Shanghai Jiao Tong University and other institutions, the university has established the "Yangtze River Delta Higher Education Alliance for Science Education," promoting the sharing of virtual simulation teaching standards and resources among multiple universities. The university has developed two Shanghai first-class courses, including "Virtual Simulation Experiment of Servo Drive for CNC Machine Tools," and one Shanghai key course, "Virtual Design and Manufacturing in Mechanical Engineering." These courses cover 14 majors across seven colleges both on and off campus, with an annual enrollment exceeding 1,200 students. Through the integration of artificial intelligence and virtual simulation technologies, the university has been granted the "Shanghai Professional Technical Service Platform for Intelligent Maintenance of CNC Machine Tools," serving equipment manufacturing enterprises across the Yangtze River Delta region and nationwide. In long-term partnerships with Shanghai Electric and Shanghai Machine Tool Works, the university has co-authored the industry-education integration textbook "Virtual Design and Manufacturing in Mechanical Engineering," which has been selected as a "14th Five-Year Plan" textbook by the China Machinery Industry Education Association. The university has also led seven Ministry of Education industry-education collaborative education projects, annually supplying over 50 talents to leading enterprises such as Shanghai Electric and COMAC.

4. Conclusion

The National Virtual Simulation Experimental Teaching Center for Equipment Manufacturing at the University of Shanghai for Science and Technology has been actively advancing the reform of cross-stage virtual simulation experimental teaching empowered by intelligent technologies. Through the establishment of boundaryless virtual simulation experimental teaching scenarios, the sharing of digital virtual simulation experimental teaching resources, and the construction of a cross-stage virtual simulation experimental teaching system, the center has achieved data sharing, knowledge interconnection, and intelligent education. This initiative fully leverages the advantages of virtual simulation technology across different stages, disciplines, and temporal-spatial dimensions, thereby promoting the comprehensive and high-quality cultivation of talent.

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