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ADVANTAGES AND CHALLENGES OF VIRTUAL REALITY TECHNOLOGY IN COLLEGE PSYCHOLOGY TEACHING

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Abstract: With the rapid development of technology, psychology teaching has begun to combine with virtual simulation technology, mainly involving aspects such as psychotherapy, cognitive psychology, human factors psychology, educational psychology, and experimental teaching. This combination has many advantages: creating an immersive learning environment, enhancing the external validity of psychological experiments, and improving teaching effectiveness; the virtual technology is diverse, has a high degree of freedom, and can reduce costs; teachers and students can experience a strong sense of reality, thus being more likely to engage in teaching; using modern technology to record real-time data, ensuring the authenticity, accuracy, and convenience of teaching data; having higher openness and sharing. However, when applying it, some issues need to be noted: the application of virtual reality technology should have real teaching needs; virtual reality teaching should be operable, and efforts should be made to increase the cultivation of relevant talents; attention should be paid to ethical issues such as the impact of virtual reality technology on relevant personnel; virtual reality technology faces the dilemma of cost-effectiveness and sustainable development. Finally, in view of the advantages and problems of virtual reality technology in psychology teaching, suggestions and research directions are proposed.
Keywords: Virtual reality technology; Psychology teaching; Advantages; Challenges

1 INTRODUCTION

Many countries around the world have explicitly stated their intention to promote the deep integration of new technologies with education and teaching [1]. This has pointed out the direction for the reform of psychology teaching in universities. Especially in today's era of rapidly advancing science and technology, new technologies are constantly being integrated into psychology teaching. These new technologies, particularly the integration of computer technology, have played a significant role in promoting the convenience and scientific nature of psychology teaching. In recent years, researchers have also applied virtual reality technology (VRT) to theoretical and experimental teaching in psychology. This application has played a huge role in promoting psychology teaching and the development of the psychology discipline. Virtual reality technology refers to the combination of computer technology and virtual simulation technology. It uses computer simulation technology, sensing technology, three-dimensional graphics technology, display technology, etc. to generate a realistic three-dimensional sensory world including hearing, vision, smell, and touch.

Psychology, as a modern science, studies human cognitive, emotional and emotional, willpower and other psychological processes as well as the occurrence, development and changes of personality. Based on its disciplinary nature, virtual reality technology can be utilized to make up for the deficiencies in traditional psychology teaching. The application of virtual reality technology has advantages such as visualization and interactivity, which can complement the shortcomings of traditional psychology teaching. Virtual reality technology has been developed abroad for several decades and has had a significant promoting effect on the development of the psychology discipline, especially in the fields of psychological therapy and cognition. The application of virtual simulation technology in psychology teaching in China has just begun. We should recognize the advantages of virtual reality technology and continuously promote the integration of virtual reality technology and psychology teaching. Of course, we should also identify the existing problems and pay attention to them in future development.

2 APPLICATION OF VIRTUAL REALITY TECHNOLOGY IN PSYCHOLOGY TEACHING

Virtual reality technology is profoundly transforming the landscape of psychology teaching in universities. The traditional psychology teaching process is limited by factors such as equipment, venue, and safety, making many important experiments difficult to conduct in the classroom. VR technology, by constructing virtual laboratories, enables students to freely carry out various psychological experiments. Researchers in psychology around the world have mainly applied virtual reality technology in five areas: psychotherapy, cognitive psychology, human factors psychology, educational psychology, and interpersonal relationship psychology [2].

2.1 Psychotherapy Teaching

This mainly occurs when treating psychological disorders such as phobias and anxiety disorders. Virtual reality technology can simulate individual fear and anxiety scenarios, and then combine psychological treatment methods (such as systematic therapy, full immersion therapy, etc.) to treat individuals. For example, when treating acrophobia, the virtual reality technology can simulate different levels of high-risk situations according to the treatment stages of the therapist, which is something that traditional methods cannot achieve.

2.2 Cognitive Psychology Teaching

Mainly focuses on neural network research and general cognitive research. The research content involves facial and verbal cognition, spatial cognition, perception, cognitive load, etc. It can simulate the required materials, experimental scenarios, and experimental conditions for experiments using virtual reality technology.

2.3 Human Factors Psychology Teaching

Mainly involves aerospace engineering, automotive and aircraft driving, human-computer interaction, and game psychology. It can simulate driving scenarios, machine interfaces, game interfaces, etc., which are difficult to obtain or costly to acquire, thereby saving costs and achieving research goals.

2.4 Educational Psychology Teaching

Virtual reality technology in the educational psychology field mainly involves learning psychology and teaching psychology. The research content includes verbal information, cognitive strategies, intellectual skills, motor skills, etc. For example, it can simulate various teaching scenarios to see which teaching scenario is rated higher by students, or to see in which teaching scenario students show better learning interest and motivation, and have a better learning state, etc.

2.5 Interpersonal Interaction

Mainly involves interpersonal relationship psychology, interaction expressions and actions, body language, and crowd behavior, etc. For example, the interaction performance of the subjects in the virtual crowd environment, helping behavior, etc. can be observed, which can be used as independent variables or dependent variables for certain experiments.

3 ADVANTAGES OF VIRTUAL REALITY TECHNOLOGY IN PSYCHOLOGY TEACHING

3.1 Creating an Immersive Learning Environment, Enhancing the External Validity of Psychological Experiments, and Improving Teaching Effectiveness

In theoretical teaching, virtual simulation technology can be utilized for the production of courseware, demonstration of principles, and other virtual simulation teaching designs. This immersive learning environment enables students to better understand certain psychological theories and principles [3].

In experimental teaching, two concepts are involved: internal validity and external validity. Internal validity refers to the degree of revealing and explaining the causal relationship between experimental variables, indicating the accuracy of the experimental research; external validity refers to the extent to which the experimental research results can be generalized to real situations, indicating the effectiveness of the experimental research. There is often a trade-off between internal validity and external validity. The stricter the control of additional variables, the greater the gap from the real situation, and the less the experimental research results can be applied to real scenarios.

Traditional psychological experiments strictly control additional variables and examine the influence of independent variables on dependent variables, ensuring internal validity. However, the problem is that this manipulation of the subjects weakens the generalization, promotion, and effectiveness of the experimental research results. The ultimate goal of psychological research should be application, which leads to the ineffectiveness of traditional psychological experiments. The emergence of virtual reality technology can precisely solve this problem. Through virtual reality technology, experimental scenarios that are infinitely close to the real situation can be simulated. The experimental conclusions obtained in this scenario naturally have greater external validity and can improve teaching effectiveness.

3.2 Virtual Technology is Diverse, has a High Degree of Freedom, and can Reduce Teaching Costs

From the current combination of virtual reality technology and psychology teaching, it can be roughly divided into four types of virtual simulations: virtual simulation of psychological processing, virtual simulation of special subject groups, virtual simulation of brain structure and function, and virtual simulation of specific experimental scenarios. These simulations mainly depend on computer technology and data simulation, mainly involving personnel and technology investment. Compared with the large-scale instruments and equipment required by traditional teaching, virtual simulation technology can not only achieve flexibility and freedom while ensuring teaching effectiveness, but also has a relatively lower cost.

Traditional psychology teaching requires actual experimental instruments and equipment, which need to be purchased and used repeatedly, resulting in high costs [4]. However, virtual reality technology is only a technological transformation, and multiple virtual reality experiments can be conducted on the same computer, and the same software or system can be used infinitely. On the other hand, traditional laboratories also require the organization, maintenance, and preparation before experiments, while virtual reality technology experiments are all computer programs, which are convenient to organize and greatly reduce the cost of experiment operation and management.

3.3 Using Modern Technology to Record Real-Time Data to Ensure the Authenticity, Accuracy, and Convenience of Teaching Data

The traditional teaching process often occurs before, and the export and analysis of teaching data often occur after. This is not conducive to real-time monitoring of data during the teaching process, making it difficult to promptly identify errors that occur during the teaching process, ultimately resulting in low teaching effectiveness. Virtual reality technology experiments can overcome this defect. During the teaching process, data generation can be monitored at any time, and data can be exported immediately after the experiment is completed for data analysis.

3.4 Higher Openness and Sharing

The combination of virtual simulation technology and network technology can break the limitations of time and space, and as long as there is a network, learning and experiments can be conducted anytime and anywhere through computer terminals or mobile phone terminals. Moreover, as long as the server has sufficient storage and network traffic, theoretically, it can infinitely meet the learning and experimental needs of countless students. This can make virtual reality teaching projects have higher openness and sharing, thereby reducing the cost of virtual reality technology.

4 ISSUES TO BE NOTED IN THE APPLICATION OF VIRTUAL REALITY TECHNOLOGY IN PSYCHOLOGY TEACHING

4.1 The Application of Virtual Reality in Teaching should have a Genuine Demand

One must truly understand the core purpose, internal basic principles and logic of the psychology teaching content. There is indeed a necessity to apply virtual reality technology in the teaching process. What are the advantages and disadvantages of virtual reality technology teaching compared to traditional teaching? How does the cost of virtual reality technology teaching compare to that of traditional teaching? These factors should all be comprehensively considered. For example, some psychological experiments have no necessity for virtual simulation. One should avoid following trends or policies blindly.

4.2 Virtual Reality Teaching should be Operable and Efforts should be made to Increase the Cultivation of Relevant Talents

The development of educational technology should take into account the level of educational technicians and teaching personnel. The development of virtual simulation equipment should be made into automatic and easy-to-use types to make it easier for psychology teachers to operate. At the same time, efforts should be made to cultivate talents in virtual reality technology, especially those with interdisciplinary expertise between virtual reality technology and psychology. This will facilitate the deep integration and professionalization of virtual reality technology and psychology teaching, promote the development of the psychology discipline, and facilitate the faster and better application of the discipline.

4.3 Ethical issues such as the impact of virtual reality technology on teachers, students, and subjects should be noted.

Sometimes, teachers apply virtual reality technology in psychology teaching due to ethical issues, but it is necessary to be aware that new ethical issues may arise during the application. Because virtual simulation experiments have high simulation and high involvement, some virtual simulation technologies may bring negative impacts to teachers, students, and subjects. For example, experiments simulating theft and murder (similar to the "Grand Theft Auto" game), subjects may suffer serious physical and mental damage after participating in the experiments [5].

4.4 Cost-Effectiveness and Sustainable Development Dilemma

The initial investment for VR teaching projects is huge, including hardware procurement, software development, and site renovation. The unit price of high-performance VR workstations is between 20,000 and 50,000 yuan. Building a 20-station VR laboratory requires investment of several million yuan. In addition, the development cost of customized psychology VR teaching content is usually 30,000 to 50,000 yuan per class, and the development of a complete course system requires several million yuan [6]. Such high costs have deterred many universities.

From the perspective of maintenance costs, VR equipment updates and replacements are fast, and a comprehensive upgrade is needed every 3 to 5 years; the license fees for professional software are high and require regular renewal; VR classrooms require a dedicated operation and maintenance team, and the human cost is considerable [7]. These continuous investments place pressure on university finances. A case from a certain university in the central and western regions shows that the annual operation and maintenance cost of its VR psychology laboratory accounts for 35% of the

total budget for teaching equipment in the college, seriously occupying other teaching resources [8].
The imperfect sharing mechanism also affects cost-effectiveness. Theoretically, VR resources can be shared across universities through the network, but due to factors such as inconsistent technical standards, intellectual property protection, and network bandwidth, the actual sharing is limited. The phenomenon of each school acting independently and repeating construction is widespread, resulting in resource waste. The establishment of a regional or national psychology VR teaching resource sharing platform requires top-level design and policy support.

5 CONCLUSION AND OUTLOOK

5.1 Research Conclusion

This study systematically examined the current application status, advantages, and problems of virtual reality technology in the reform of psychology teaching in universities, and reached the following main conclusions:
Firstly, VR technology has brought revolutionary changes to psychology teaching. By constructing immersive learning environments, VR technology effectively solved the problems in traditional psychology teaching such as the difficulty in understanding abstract concepts, limited experimental conditions, and insufficient practical opportunities. It demonstrated significant advantages in enhancing learning motivation, promoting deep understanding, and cultivating practical abilities, which are highly consistent with the development trend of higher education informatization.
Secondly, the application of VR technology shows a diversified feature. In experimental teaching, VR technology expands the scope and accessibility of experiments through virtual laboratories; in theoretical teaching, three-dimensional visualization makes abstract concepts intuitive and tangible; in skill training, simulation environments provide students with safe repeated practice opportunities. These applications are reshaping the teaching ecosystem of psychology and promoting the transformation of teaching paradigms from knowledge transmission to experiential learning.
However, the in-depth application of VR technology still faces multiple challenges. The insufficient maturity of technology limits the full display of teaching effects; the shortage of teaching staff leads to insufficient integration of VR teaching with the curriculum system; ethical risks and management issues require the establishment of new norms; the high cost restricts the popularization and promotion of VR teaching. These issues need to be addressed through systematic strategies.

5.2 Future Outlook

With the continuous progress of technology and the update of teaching concepts, the application of VR technology in psychology teaching in universities will present the following development trends:
From the perspective of technology, lightweight and intelligent will be the development direction. Future VR devices will be more lightweight and comfortable, eliminating the current problem of dizziness; the integration of artificial intelligence technology will enable VR systems to have stronger interaction capabilities and adaptability, able to adjust teaching content and difficulty in real time based on students' performance. The popularization of 5G networks will support cloud rendering, reducing the performance requirements of terminal devices, making VR teaching more widespread [9].
In terms of application models, mixed reality (MR) and augmented reality (AR) technologies will be combined with VR to create more flexible learning experiences. Students can interact with virtual objects in the real classroom, achieving seamless mixed learning. This model can retain the social interaction advantages of face-to-face teaching while obtaining the immersive experience of the virtual environment, possibly becoming the mainstream form of psychology teaching in the future.
From the perspective of educational ecology, VR technology will promote the in-depth development of cross-university collaboration and resource sharing. Blockchain technology-based resource certification and trading platforms may emerge, enabling universities to safely and efficiently share VR teaching resources. A national virtual simulation experiment teaching alliance for psychology is expected to be established, setting unified standards and coordinating resource development to avoid redundant construction.
In terms of talent cultivation, interdisciplinary collaboration will be deeper. More universities will establish interdisciplinary majors of psychology and information technology to cultivate compound talents who understand both psychological principles and VR technology [10]. Closer cooperation between enterprises and universities will be formed, creating an integrated talent cultivation ecosystem. This trend will fundamentally solve the problem of shortage of VR psychology teaching talents.

5.3 Research Suggestions

Based on the findings of this study, the following suggestions are proposed for the reform of psychology teaching in universities:
Produce VR technology applications in stages. Universities with mature conditions can fully build VR laboratories and systematically develop corresponding teaching resources; universities with limited conditions can start from individual courses as a pilot, gradually accumulating experience. Different universities should choose suitable application paths based on their own positioning and characteristics, avoiding blind following.

Attach equal importance to teaching research and technological innovation. Encourage teachers to conduct action research on VR teaching effects and explore best practices. The research topics could include: the impact of different VR teaching designs on learning outcomes; the interaction patterns between teachers and students in the VR environment; the appropriate duration and frequency of VR teaching, etc. Such research will provide empirical evidence for the optimization of VR teaching.

Establishing a quality assurance system is of vital importance. This includes technical standards for VR teaching resources, teaching design norms, ethical review mechanisms, and effect evaluation plans, etc. Professional organizations such as the Psychology Teaching Guidance Committee can take the lead in formulating relevant standards and guiding the healthy development of VR teaching.

In conclusion, virtual reality technology provides a powerful impetus for the reform of psychology teaching in universities. However, its application is a systematic project that requires the joint efforts of educators, researchers, technicians, and managers. Only by adhering to the "student-centered" concept and balancing technological innovation with educational laws can the transformative potential of VR technology be truly exploited, and psychology talents who can meet the demands of the digital age be cultivated.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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TEACHING MODE OF "FUNDAMENTALS OF ELECTRICAL TECHNOLOGY" COURSE BASED ON VIRTUAL-REAL INTEGRATION

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Abstract: This study innovatively developed a "Three Integrations, Three Stages, Six Steps" teaching model for the "Fundamentals of Electrical Technology" course through virtual-real integration technology. The framework systematically addresses critical challenges in traditional education such as insufficient practical opportunities, fragmented resources, and unscientific evaluation mechanisms. By advancing through five dimensions─foundational analysis, environment construction, model innovation, resource support, and evaluation assurance ─ the model establishes a comprehensive educational reform framework with a closed-loop implementation path. Practical evidence demonstrates that this approach significantly enhances student engagement, practical skills, and teaching quality. It provides a replicable paradigm for deepening the integration of information technology and pedagogical instruction in vocational education, offering valuable reference for similar technical course reforms.
Keywords: Virtual-real integration; Fundamentals of Electrical Technology; Teaching mode; Teaching evaluation

1 INTRODUCTION

With the rapid advancement of information technology, particularly the emergence of virtual reality (VR) and augmented reality (AR), new possibilities have been created for innovative educational models. The "Education Informatization 2.0 Action Plan" highlights that educational informatization possesses unique advantages such as breaking time-space constraints, rapid replication and dissemination, and diverse presentation methods, making it a crucial tool to enhance educational quality. It emphasizes strengthening the construction of virtual simulation training environments in vocational colleges and universities to meet the needs of digital teaching[1]. The "Vocational Education Quality Improvement Action Plan (2020-2023)" advocates deep integration of information technology with education, encouraging vocational schools to leverage modern IT to reform talent cultivation models, address students' diverse learning needs, and vigorously promote new forms of "Internet+" and "Intelligent+" education, driving transformative innovations in teaching practices[2].
"Fundamentals of Electrical Technology" serves as a cornerstone course for electrical engineering majors, equipping students with essential theoretical knowledge and practical skills to prepare them for advanced studies and real-world applications. However, traditional teaching methods often overemphasize theoretical instruction while neglecting hands-on experiments and practical training. This imbalance frequently prevents students from effectively integrating theory with practice, hindering their deep understanding of electrical engineering principles and development of application capabilities. By adopting a blended learning approach that combines virtual and real-world simulations, this course not only addresses these limitations but also enhances student engagement, motivation, and ultimately cultivates innovative thinking and practical problem-solving skills[3].
Therefore, this paper aims to explore the teaching mode of "Fundamentals of Electrical Technology" based on virtual-real integration. Through building a virtual-real integrated teaching environment, optimizing teaching content and methods, developing rational-real integrated teaching resources, establishing a diversified evaluation system and other measures, the teaching quality and learning effect of the "Fundamentals of Electrical Technology" course can be comprehensively improved.

2 THE KEY PROBLEMS TO BE SOLVED

2.1 Solve the Problem of Lack of System and Integrity in the Integration of Virtual Simulation and Teaching Mode

Currently, the application of virtual simulation technology in the "Fundamentals of Electrical Technology" course remains fragmented. Virtual simulation experiments often operate independently from theoretical instruction, lacking coherence in integrating virtual and real-world elements and failing to be embedded within a complete teaching process. To address this issue, this paper proposes a "Three Integrations, Three Stages, Six Steps" teaching model that incorporates virtual simulation throughout the entire learning cycle─before, during, and after class. By categorically designing application scenarios for virtual simulations, the approach enhances the systematic integration and holistic coherence of the educational framework.

2.2 Solve the Problem of Lack of Pertinence and Practicability in the Development of Virtual Simulation Teaching Resources

The current virtual simulation teaching resources for courses lack sufficient alignment with core knowledge points, making it difficult to effectively address key teaching challenges. Moreover, the simulated scenarios are disconnected from real-world engineering contexts. To address this issue, this paper proposes a layered design of virtual tasks centered on core competencies. Furthermore, we collaborate with enterprises to develop simulation resources featuring authentic engineering cases, thereby enhancing the practicality and career-oriented relevance of these resources.

2.3 Solve the Problem that the Virtual Simulation Teaching Evaluation System Lacks Scientificity and Objectivity

Traditional evaluation methods predominantly rely on summative assessments, overemphasizing one-time test results while neglecting behavioral data from the learning process. This single-dimensional approach fails to comprehensively and authentically reflect students' academic achievements and skill development, leading to biased evaluation outcomes that hinder effective teaching optimization and learning improvement. To address this issue, this paper proposes a data-driven dynamic evaluation system that incorporates multi-dimensional assessment indicators to dynamically evaluate learning performance.

3 THE INTEGRATION OF VIRTUAL AND REAL TEACHING MODE

The integration of virtual and real-world teaching practices focuses on creating simulated authentic learning environments for students. This approach fulfills the expected practical objectives of course instruction while achieving pedagogical outcomes through immersive simulations. By deeply integrating embodied experiential learning with interactive engagement, it fosters students' immersion in the educational process and cultivates their application capabilities[4].

This project advances systematically through five dimensions: "foundational analysis, environmental construction, model innovation, resource support, and evaluation assurance". It establishes a comprehensive framework for teaching reform research. By conducting student needs assessments, optimizing curriculum standards, and setting objectives (foundational analysis), the project creates a blended virtual-real teaching environment (environmental construction). The innovative "Three Integrations, Three Stages, and Six Steps" teaching model (model innovation) is developed, complemented by a multidimensional teaching resource system (resource support). Ultimately, a dynamic, diversified evaluation mechanism (evaluation assurance) is established, forming a closed-loop teaching reform pathway. The overall idea is shown in Figure 1.

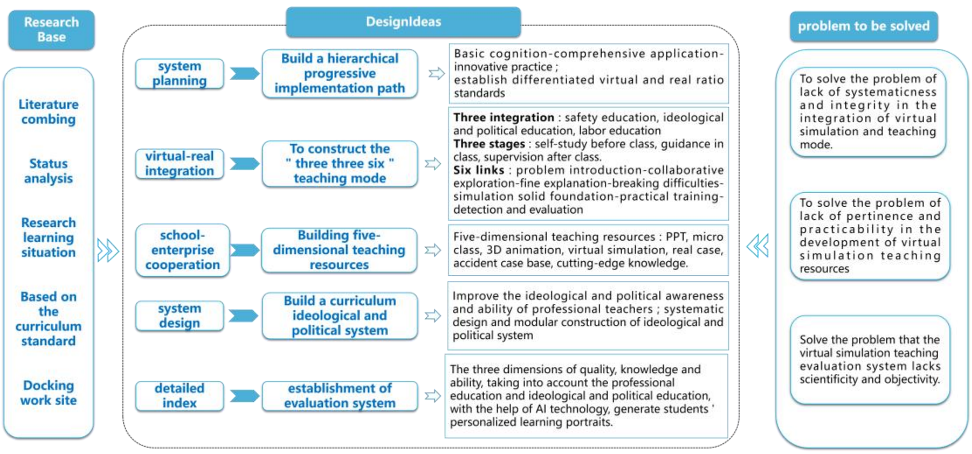

Figure 1 Overall Idea

3.1 Research and Analysis, Sorting out and Summarizing the Collected Data to Consolidate the Foundation of Virtual-Real Integration Teaching

"Fundamentals of Electrical Technology" is a core required course for electrical engineering majors, serving as a crucial program to develop students' professional competencies and ethical standards. As the primary participants in classroom activities, students should actively engage in curriculum research to identify individual differences and comprehensively address their learning needs. This approach ensures teaching resources effectively meet student requirements, enabling them to utilize learning materials appropriately and enhance their academic outcomes.

Through questionnaire survey and interview quantitative analysis, students' basic knowledge of electrical engineering, cognitive style and technical acceptance were quantified; industry enterprises were combined to sort out typical work tasks and extract core competency modules; existing training conditions were sorted out and the current situation of virtual simulation application was analyzed, so as to provide data support for the innovation of teaching mode and resource development in the future.

3.2 System Planning, Build a Hierarchical Implementation Path, and Form a Virtual and Real Integrated Teaching Environment

To address the current deficiency in deep integration of virtual and real-world elements in teaching, we have developed a tiered "basic cognition-comprehensive application-innovative practice" teaching pathway that combines virtual and physical environments, establishing virtual simulation and practical training platforms. ① The foundational layer focuses on virtual simulations, using software like Multisim for basic circuit theory training. ② The comprehensive application layer employs a hybrid approach, simulating complex system operations in virtual environments before conducting physical equipment verification. ③ The innovative layer utilizes real-world projects as carriers, leveraging virtual-real platforms to collaboratively solve open engineering challenges. We also established differentiated virtual-real integration standards, implementing progressive implementation plans for theoretical foundations, comprehensive training, and innovative projects through varying degrees of virtual-real integration, providing environmental support for subsequent teaching model implementations[5].

3.3 Build a Teaching Mode of "Three Integrations, Three Stages, and Six Steps" to Improve the System of Integration

Centered on students, aiming at the improvement of quality, knowledge and ability, and taking project tasks as the carrier, we build a teaching mode of "Three Integration, Three Stages and Six Steps".

The "Three Integrations" initiative integrates three educational dimensions throughout the teaching process: labor education, ideological-political education, and safety education. Specifically, labor education empowers students to master practical skills like electrical tool usage and wiring installation through hands-on practice, while cultivating their work ethic and dedication. Ideological-political education leverages China's world-leading achievements in ultra-high voltage power transmission technology to foster technological confidence, and showcases exemplary stories of power industry workers to instill professional values of diligence and commitment. Safety education employs VR simulations of electric shock and short-circuit scenarios to reinforce the principle of "safety first." This integrated approach creates a tripartite educational framework combining technical skills, moral cultivation, and value orientation.

The "Three Stages" framework comprises three phases: pre-class self-study, in-class guided learning, and post-class supervision. During the pre-class self-study phase, students prepare materials through preparatory work. The in-class guided learning phase employs six instructional modules: problem introduction, collaborative inquiry, detailed explanation of key concepts, simulation-based foundation reinforcement, practical skill development, and assessment evaluation. Utilizing virtual simulation technology to replicate real-world scenarios, students perform circuit assembly and fault diagnosis operations within a virtual environment. Through hands-on practice, they apply skills learned from simulations to actual equipment operation, enhancing both practical skills and engineering competencies. The post-class supervision phase involves reviewing previously acquired knowledge and completing extended learning tasks[6].

The "Six Steps" integrates virtual simulation technology throughout the entire learning process − from pre-class preparation to in-class exploration and post-class extension − forming a closed-loop learning path of "theory − virtual practice − real operation − reflection and optimization". By organically combining theoretical instruction, virtual simulations, and hands-on training, this framework establishes an integrated teaching system that seamlessly blends theoretical knowledge with practical application.

Through "Three Integration, Three Stages and Six Steps", the organic unity of knowledge transmission, ability cultivation and value guidance is realized.

3.4 School-enterprise Cooperation, Build a Five-Dimensional Teaching Resource Platform, and Form a Virtual and Real Integrated Resource Base

We have established a specialized curriculum team combining full-time and part-time faculty members from universities and enterprises. By integrating electrical and electronic training laboratories and utilizing virtual simulation software for experiments, we have developed high-quality digital teaching resources that form a five-dimensional educational framework: "Initiation, Learning, Practice, Operation, and Expansion" with clear application scenarios[7]. ① Pre-class Self-study: Develop pre-class learning resource packages to support students 'pre-class exploration and stimulate critical thinking. ② Course Platform: Leverage Shandong Electric College's digital learning platform advantages through micro-lectures, 3D animations, and virtual simulations to create personalized courses for principle-based learning. ③ Virtual Simulation: Utilize experimental simulation software to develop course-specific virtual resources focused on technical skill development. ④ Practical Training: Establish standardized real-world work environments in electrical training laboratories and create hands-on demonstration course materials for student practice.

⑤ Post-class Expansion: Develop extended learning resources based on real-world case studies and emerging electrical technology advancements to enhance knowledge retention and skill enhancement.

3.5 Taking Teachers as the Basis, the Ideological and Political Education System is Systematically Designed and Modularly Constructed to Realize Ideological and Political Education

① Enhance professional teachers 'ideological and political awareness and capabilities to build solid ideological education expertise. Strengthen course instructors' primary role in integrating ideological education into teaching, reinforce their dual focus on instruction and student development, improve teachers' political literacy, and elevate their ideological education capabilities[8]. ② Systematically design and modularize the ideological education framework. Construct a resource repository encompassing industry pioneers, contemporary role models, historical contexts, disciplinary frontiers, and national engineering projects. This repository will incorporate diverse teaching methods and concrete case studies, with layered integration according to course modules. Through multi-level ideological education integration points from modules to tasks, achieve comprehensive coverage across all dimensions[9].

3.6 Refine Indicators and Build a "Diverse, Multidimensional, Dynamic" Evaluation System to Achieve Scientific Evaluation

The assessment system evaluates students across three dimensions — quality, knowledge, and competence — while integrating professional education with ideological-political education. It establishes evaluation metrics through a combination of online learning assessments, process evaluations, and outcome-based assessments. The ideological-political assessment is embedded throughout the learning process in both implicit and explicit ways, focusing on students 'developmental changes during the learning journey and exploring value-added assessment methods. By leveraging AI to analyze massive student data collected from learning platforms, personalized learning profiles are generated to more accurately assess students' learning capabilities. This enables the provision of tailored learning recommendations, fostering self-directed learning and holistic student development.

4 RESULT AND EFFECT

4.1 The Teaching Quality has been Significantly Improved

By developing a blended teaching model for the "Fundamentals of Electrical Engineering" course featuring "Three Integrations, Three Stages, and Six Steps", we organically integrate labor education, ideological-political education, and safety education into three instructional phases: pre-class, in-class, and post-class. During the in-class phase, we employ a six-step pedagogical approach: problem introduction, collaborative inquiry, focused explanation, simulation reinforcement, practical training, and assessment evaluation, with virtual simulation technology integrated throughout the entire teaching process. This blended teaching method that combines theoretical knowledge with practical application not only enhances students' hands-on skills but also significantly improves overall teaching quality and learning outcomes.

4.2 The Teaching Resource System is More Perfect

The curriculum development has established a multidimensional teaching resource repository encompassing theoretical instructional videos, virtual simulation resources, practical demonstration materials, and interactive learning modules. Leveraging electrical and electronic simulation software alongside laboratory hardware facilities, a dual-environment teaching platform integrating virtual and real-world components has been developed. This integrated theoretical-practical-physical educational resource system provides students with enhanced learning experiences, effectively boosting both academic efficiency and engagement.

4.3 The Teaching Evaluation System is More Scientific

We have innovatively developed a comprehensive evaluation system that is diversified, multidimensional, varied, and dynamic. By integrating multi-source data from virtual platforms, we fully leverage the guiding, motivating, diagnostic, and improvement functions of evaluations. The established dynamic evaluation mechanism provides real-time feedback on teaching information, offering data-driven support for instructional optimization and student development. This approach achieves scientific precision in educational assessment.

5 CONCLUSION

This study develops a "Three Integrations, Three Stages, and Six Steps" teaching model for the Electrical Engineering Fundamentals course through virtual-real integration technology. By implementing systematic instructional design, multidimensional resource development, and dynamic evaluation systems, the model has significantly enhanced both teaching quality and student learning outcomes. Practical results demonstrate that this blended approach not only addresses shortcomings in traditional teaching's practical components but also significantly improves students' theoretical comprehension, hands-on skills, and innovative thinking through immersive, interactive learning experiences. The virtual-real integration model provides fresh perspectives for curriculum reform in Electrical Engineering Fundamentals while injecting new momentum into the digital transformation of vocational education. Moving forward, we will continue refining this model to contribute to cultivating highly skilled technical professionals.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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STUDENT BEHAVIOR ANALYSIS IN SMART CLASSROOMS: CURRENT TRENDS AND FUTURE DIRECTIONS

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Abstract: This study examines the current status and future prospects of student behavior analysis in smart classrooms, with a focus on the context of educational informatization, the impact of artificial intelligence on education, the process of learning behavior analysis, the application of relevant technologies, the present state of behavior classification, and associated research achievements and applications. Against the backdrop of educational digital transformation, smart classrooms integrate big data and artificial intelligence to enable precise monitoring and analysis of students' learning behaviors, thereby providing essential support for personalized instruction. Research findings indicate that smart classrooms can effectively enhance students' classroom attention and engagement, while assisting teachers in better understanding learning conditions and optimizing instructional strategies. Nevertheless, practical implementation still faces numerous challenges, including technology reliability and data privacy protection. Future research should further expand the diversity and coverage of data sources, emphasize the application of multimodal data fusion analysis, and explore the role of smart classrooms in promoting educational equity and personalized teaching, in order to advance the development of smart education.
Keywords: Smart classrooms; Patterns of student behavior; Educational informatization

1 INTRODUCTION

1.1 Educational Digital Transformation

With the rapid advancement of information technology, the field of education is undergoing an unprecedented digital transformation. This transformation has not only reshaped traditional educational models, but has also had a profound impact on teaching methods and learning behaviors. Against the broader backdrop of educational informatization, the smart classroom—as an emerging instructional paradigm—has gradually become a focal point of both research and practice. By integrating big data, artificial intelligence, and other advanced technologies, smart classrooms enable precise monitoring and analysis of students' learning behaviors, thereby providing essential support for personalized instruction [1]. Meanwhile, although many universities in China have introduced intelligent technologies into classroom teaching, the overall level of informatization remains insufficient, leaving substantial room for the further development of smart classrooms [2]. Research shows that smart classrooms can effectively enhance students' classroom attention and engagement, while helping teachers better grasp learning conditions and optimize instructional strategies. Thus, educational digital transformation is not merely a technological innovation, but also a profound shift in educational philosophy and teaching practice.

From a macro perspective, the significance of educational digital transformation lies in its dual role in promoting educational equity and quality. On one hand, the application of digital technologies facilitates the widespread dissemination of high-quality educational resources, alleviating disparities in educational access across regions. On the other hand, data-driven teaching models help realize individualized instruction, meeting the learning needs of students with diverse abilities [1]. Furthermore, smart classrooms, through multi-dimensional data analysis, provide a scientific basis for educational decision-making, thereby improving the efficiency and accuracy of educational management [2]. Nevertheless, despite the significant theoretical advantages of smart classrooms, their practical implementation still faces numerous challenges, such as technology reliability and data privacy protection. Addressing these issues requires joint efforts from both academia and practitioners to advance educational digital transformation in depth.

1.2 Directives from the Report of a Major National Policy Meeting in 2022

The Report of a major national policy meeting in 2022 explicitly proposed the strategic plan to promote educational digitalization, which provides clear direction for the development of the education sector and offers important guidance for the construction of smart classrooms. The report emphasizes that educational digitalization is a crucial pathway to achieving educational modernization and a key lever for promoting high-quality educational development [3]. Against this backdrop, the smart classroom—serving as a concrete practice of educational digitalization—aims to realize intelligent and personalized teaching processes through technology empowerment. The realization of this goal depends on in-depth analysis of students' learning behaviors in class; only by accurately grasping students' learning states and behavioral characteristics can reliable evidence be provided for instructional improvement [4].

From a policy perspective, the report of the 20th National Congress offers strong support for the development of smart classrooms. First, the Digital China strategy proposed in the report has created a favorable external environment for the technological innovation and application of smart classrooms. Second, the report's call to accelerate the construction of a high-quality education system further underscores the potential of smart classrooms to enhance educational quality [3]. In addition, the construction of smart classrooms is highly aligned with the report's vision of promoting educational equity, as it leverages technology to reduce the urban–rural education gap and advance balanced educational development [4]. Nevertheless, the promotion and application of smart classrooms still face a series of practical challenges, such as improving teachers' information literacy and ensuring the widespread availability of technical equipment. Overcoming these issues requires coordinated efforts from the government, schools, and all sectors of society to ensure the smooth implementation of the educational digitalization strategy.

2 THE IMPACT OF ARTIFICIAL INTELLIGENCE ON EDUCATION

2.1 Opportunities

The rapid development of artificial intelligence (AI) has brought unprecedented opportunities to the field of education, particularly in personalized instruction and precision assessment. By leveraging deep learning algorithms and data mining technologies, smart classrooms can generate individualized learning pathways and resource recommendations based on students' learning behaviors, interest preferences, and knowledge mastery levels [1]. This personalized teaching model not only meets the diverse learning needs of students, but also alleviates, to some extent, the limitations of the "one-size-fits-all" approach prevalent in traditional classrooms. Furthermore, AI demonstrates significant advantages in precision assessment. Through the analysis of multimodal data from the learning process—such as speech, images, and text—teachers can gain a more comprehensive understanding of students' learning states and progress trends, thereby formulating more targeted instructional strategies [5]. The application of these technologies not only improves the quality of education and teaching but also provides new possibilities for achieving educational equity.

2.2 Challenges

Despite the promising prospects of AI in education, its widespread adoption faces numerous challenges, with data privacy and technology reliability being the most prominent. In smart classrooms, students' learning behavior data are extensively collected and analyzed, inevitably raising concerns about data security and privacy protection [2]. For example, students' personal information and learning records may be misused or leaked, compromising their rights and interests. In addition, the reliability of AI technologies remains an urgent issue. Due to the complexity of algorithms and the inconsistency of data quality, AI systems may, in some cases, fail to provide accurate analytical results, and may even lead to erroneous decisions [6]. To address these challenges, it is necessary to establish robust data protection mechanisms and algorithm validation systems from technical, legal, and ethical perspectives, ensuring the safety and trustworthiness of AI in the educational context.

2.3 Research Necessity

Research on the use of AI to analyze students' learning behaviors in the classroom holds significant theoretical and practical value. First, in-depth analysis of learning behaviors can help teachers better understand students' learning processes and needs, thereby optimizing instructional design and improving teaching effectiveness [3]. Second, the application of AI can provide more refined and comprehensive data support for educational research, promoting the development of educational science. For example, big-data-based learning behavior analysis can reveal patterns in student learning and lay the foundation for building a scientific learning evaluation system [7]. Moreover, within the current context of educational digital transformation, the construction of smart classrooms has become an important direction of educational reform, with AI serving as a key driver in achieving this goal. Therefore, strengthening research on the application of AI in education not only helps solve existing problems in teaching but also offers important insights for the innovation of future educational models.

3 PROCESS OF STUDENT LEARNING BEHAVIOR ANALYSIS IN SMART CLASSROOMS

3.1 Construction of a Learning Behavior Classification System

The construction of a learning behavior classification system forms the foundation of student behavior analysis in smart classrooms, and its scientific validity and rationality directly affect the depth and breadth of subsequent research. By employing the literature analysis method and integrating existing research findings, nine categories of learning behaviors can be summarized, encompassing dimensions such as verbal learning activities, positional movement, physical actions, and technology use [3]. The basis for these classification systems primarily stems from the integration and analysis of multimodal data—including audio data, image data, and text data—within a three-dimensional framework, thereby providing a comprehensive perspective for characterizing learning behaviors [2]. Furthermore, drawing on the achievements of research on learning behavior classification systems, the definitions and boundaries of behavior types have been further refined to ensure the rationality and operability of the system. This classification approach not only reflects students' behavioral characteristics in the classroom but also lays the groundwork for subsequent data coding and qualitative analysis.

3.2 Data Collection

Data collection is a crucial stage in the analysis of students' learning behaviors in smart classrooms, and its quality directly influences the reliability of research results. In this study, Ministry-level "One Teacher, One Excellent Lesson" platform video data of exemplary lessons served as the primary source, from which a student behavior dataset was systematically constructed. Specifically, the scope of data collection covered classroom teaching videos, teacher–student interaction records, and student technology usage logs, representing diverse multimodal data [5]. In terms of selection criteria, priority was given to high-quality, representative course videos to ensure both data quality and diversity. The data collection process included three stages: video recording, data annotation, and data cleaning. In the annotation phase, a hybrid approach combining manual and automated annotation was adopted to improve efficiency and accuracy. The resulting student behavior dataset provides abundant material for subsequent target tracking and detection model training.

3.3 Target Tracking and Detection Model Training

Target tracking and detection model training constitute one of the core technologies for analyzing students' learning behaviors in smart classrooms, and their performance determines the accuracy and efficiency of behavior recognition. This study employed the DeepSORT algorithm for target tracking and combined it with the YOLOv5 object detection algorithm to train the detection model. DeepSORT integrates appearance features with motion information for target tracking, effectively addressing challenges such as target occlusion and rapid movement in complex scenes [8]. YOLOv5, renowned for its high detection speed and accuracy, is particularly well-suited for real-time object detection in video streams. In this study, the integration of these two algorithms significantly improved the accuracy and real-time performance of student behavior recognition. Specifically, YOLOv5 was first used to detect behavioral targets, followed by DeepSORT to track the detected targets, thereby enabling continuous monitoring and analysis of student behaviors. This technical combination not only enhanced the robustness of the model but also provided reliable data support for subsequent multi-perspective analysis.

3.4 Multi-Perspective Analysis Methods

Multi-perspective analysis methods are essential tools for analyzing student learning behaviors in smart classrooms, as their synergistic use can reveal deeper behavioral patterns. This study incorporated S–T classroom teaching behavior analysis and temporal sequence analysis of student behaviors to comprehensively characterize students' learning behavior profiles. S–T classroom teaching behavior analysis involves statistical examination of the proportion and frequency of teacher and student behaviors, revealing the correlations between different behavior types and their impact on teaching effectiveness [9]. For example, the study found that in award-winning lesson cases, the proportion of teacher lecturing behaviors was higher than in ordinary lessons, while students' technology usage behaviors were relatively lower—indicating that teacher-led instructional models still hold a dominant position in smart classrooms. Meanwhile, temporal sequence analysis of student behaviors identifies patterns and variations in behavior sequences, offering insights into the dynamics of students' learning behaviors [10]. The integration of these two methods enhances the comprehensiveness of the analysis and provides a scientific basis for optimizing instructional strategies.

4 CURRENT STATUS OF STUDENT BEHAVIOR ANALYSIS IN SMART CLASSROOMS

4.1 Application of Technologies

In recent years, the application of technologies for student behavior analysis in smart classrooms has shown a trend toward the deep integration of multimodal data technologies and artificial intelligence (AI) algorithms. Multimodal data technologies integrate various types of data—such as audio, image, and text—to support comprehensive monitoring of students' learning behaviors. For example, Jiang Jie and colleagues proposed a multimodal data analysis method based on an "audio–image–text" three-dimensional framework to capture behavioral characteristics such as verbal learning activities, positional movement, physical actions, and technology use in smart classrooms [3]. Audio data have been widely applied to analyze the relevance between students' discussion content and the course, while video data can effectively reflect students' concentration and emotional states during collaborative learning [11]. At the same time, AI algorithms such as the DeepSORT target tracking algorithm and the YOLOv5 object detection model further enhance the accuracy and efficiency of behavior recognition. The combination of these technologies not only enables real-time monitoring of student learning behaviors but also provides a reliable foundation for subsequent data analysis and instructional decision-making.

Nevertheless, despite the growing maturity of technological methods, their application still faces certain limitations. On one hand, the collection and processing of multimodal data require high-performance hardware devices, which to some extent hinders widespread adoption. On the other hand, compatibility and standardization issues between different technologies remain unresolved, increasing the complexity of data integration and analysis. In the future, with further advancements in the Internet of Things (IoT) and intelligent sensing technologies, the technical framework for student behavior analysis in smart classrooms is expected to become more complete, thereby better serving educational practice [2].

4.2 Current Status of Behavior Classification

Current research on student behavior classification in smart classrooms mainly focuses on the construction of behavior classification systems and their accuracy. Using the literature analysis method, Jiang Jie and colleagues summarized nine categories of learning behaviors, including asking questions, note-taking, assignment completion, and test participation, providing an important theoretical basis for subsequent studies [3]. However, existing classification systems still face multiple challenges in practical application. First, the accuracy of behavior classification depends on high-quality datasets, and issues such as sample bias or annotation errors during data collection may affect the reliability of classification results. Second, the boundaries between certain behavior types are ambiguous; for example, distinguishing between active thinking and passive listening can be difficult, potentially leading to inconsistent classification outcomes [2].

Furthermore, the comprehensiveness of behavior classification has been questioned. Existing systems mainly focus on students' explicit behaviors, with limited coverage of implicit behaviors such as emotional states and cognitive load. This limitation may lead to an incomplete understanding of students' learning behaviors, thereby affecting the formulation and optimization of instructional strategies. Therefore, future research should improve existing classification systems while exploring methods to identify and categorize behavioral features from additional dimensions, in order to enhance the comprehensiveness and scientific rigor of behavior analysis [3].

4.3 Research Achievements and Applications

Research on student behavior analysis in smart classrooms has already demonstrated significant value in educational practice. By conducting in-depth analyses of students' learning behaviors, researchers can reveal the relationship between behavioral patterns and learning outcomes. For instance, Le Qiqing and colleagues, through visual analysis of learning data from an Automobile Structure and Assembly course, found that students' online questioning frequency, assignment scores, and classroom knowledge mastery rate were significantly positively correlated with their final grades [4]. Similarly, Zhang Jiali and colleagues, in a study on engagement in collaborative learning within smart classrooms, confirmed that multimodal-data-based analytical models can effectively assess students' learning engagement levels and provide teachers with precise bases for instructional intervention [7].

In terms of practical application, research outcomes from smart classroom student behavior analysis have been widely adopted in areas such as academic achievement diagnosis, personalized instructional recommendations, and instructional strategy optimization. For example, by analyzing behavioral data from smart classrooms, teachers can promptly identify students' learning difficulties and take targeted measures to improve instructional effectiveness. Moreover, learning behavior analysis based on multimodal data can offer valuable references for educational researchers to construct scientific learning evaluation systems, further driving innovation and development in educational models [3, 11]. However, it is worth noting that the actual effectiveness of these research applications remains constrained by factors such as implementation costs, teachers' professional competence, and schools' informatization levels. Therefore, future efforts should focus on improving support mechanisms to promote the broader dissemination and application of research results [2].

5 CONCLUSIONS ON STUDENT BEHAVIOR ANALYSIS IN SMART CLASSROOMS

5.1 Summary of Behavioral Patterns

Through in-depth research on students' learning behaviors in smart classrooms, a series of notable behavioral patterns have been identified. First, there is a certain correlation between class size and the proportion of teacher lecturing behaviors. Studies show that as the number of students in a smart classroom increases, the proportion of teacher lecturing tends to decline, while the proportion of technology-related behaviors and student self-directed learning behaviors increases [10]. This phenomenon may be related to the technological support features of smart classrooms, where teachers are more inclined to leverage information technologies to compensate for the limitations of traditional lecture-based methods, thereby promoting personalized learning. Second, the proportion of teacher guidance behaviors is closely associated with the frequency of student active behaviors. Research indicates that when teacher guidance behaviors increase, student active behaviors—such as hands-on practice, active thinking, and technology operations—also rise significantly, suggesting that teacher facilitation plays a key role in shaping students' behavioral patterns [12]. Furthermore, students in smart classrooms generally exhibit high levels of technology operation behaviors. Notably, in ordinary lesson cases, the proportion of technology-related behaviors reached 32.97%, far exceeding the 23.19% observed in award-winning lesson cases [10]. This data reflects students' strong reliance on technology in smart classrooms and reveals a potential link between technology use efficiency and instructional effectiveness.

5.2 Implications for Teaching and Learning

The behavioral patterns identified above carry important implications for educational practice. First, teachers should flexibly adjust instructional strategies based on class size and students' behavioral characteristics. For instance, in large-class teaching, teachers can enhance student engagement by using interactive tools provided by smart platforms—such as online quizzes and discussion forums—while reducing reliance on a single lecture format [7]. Second, teachers should emphasize the diversity and specificity of guidance behaviors to stimulate students' initiative and creativity. Research findings show that teacher observation and guidance behaviors in smart classrooms can significantly enhance students' learning engagement, especially in behavioral, emotional, and cognitive dimensions [13]. Therefore, teachers should make full use of technological means during instruction to promptly identify students' learning needs and provide effective feedback. Additionally, the use of technology in smart classrooms should aim to facilitate deep learning, rather than remaining at a superficial operational level. Teachers should design more technology-based inquiry activities to guide students from passive reception to active exploration, thereby improving teaching effectiveness.

5.3 Practical Application Recommendations

To further optimize student learning behaviors in smart classrooms, the following recommendations are proposed. First, teachers should incorporate more student-centered activities into instructional design, such as collaborative learning and project-based learning, to enhance students' cooperative awareness and self-learning capabilities [14]. Second, schools should strengthen teacher training in information technology to help educators master the tools and methods of teaching in smart classroom environments, thus better supporting students' learning processes [6]. Furthermore, the functional design of smart classroom platforms should better align with students' actual needs—for example, by delivering personalized learning resources that match different students' progress and interests. Studies have shown that the accuracy of personalized content delivery directly affects students' learning experiences and outcomes; therefore, platform developers should continuously improve algorithms to enhance the intelligence level of resource recommendation [6]. Finally, teachers should make full use of classroom behavior analysis data, applying methods such as lag sequence analysis to uncover patterns and trends behind student behaviors, thereby providing a scientific basis for instructional decision-making [12]. These measures will help create a more efficient and interactive smart classroom environment, ultimately achieving both students' holistic development and comprehensive improvement in teaching quality.

6 RESEARCH LIMITATIONS AND PROSPECTS

6.1 Research Limitations

Although this study has achieved certain results in the field of student behavior analysis in smart classrooms, several inevitable limitations remain. First, in terms of research methodology, this study mainly relies on the literature analysis method and data mining techniques. While these approaches can extract valuable information from existing research, they may overlook certain practical cases that have not been fully documented or published, thereby affecting the comprehensiveness of the research results [3]. Second, regarding data collection, the research data primarily come from Ministry-level "One Teacher, One Excellent Lesson" platform exemplary lesson videos. Although these data possess a degree of representativeness, their sample scope is relatively limited, making it difficult to fully capture the diversity of different regions, schools, and student populations. Moreover, due to the complexity of data annotation and processing, the accuracy of certain behavioral data may be affected by human factors, which in turn may constrain the reliability of the analysis results [2].

In terms of research scope, this study mainly focuses on the analysis of students' learning behaviors in smart classroom settings, with relatively less attention to other educational contexts such as online education and blended learning. This limitation may reduce the generalizability of the research conclusions, preventing them from fully reflecting the overall situation of student behavior analysis under the broader background of educational informatization. Furthermore, due to technical constraints, this study has not fully explored the potential value of multimodal data fusion analysis in behavior monitoring—particularly in areas such as emotion recognition and physiological signal analysis, where in-depth applications remain insufficient. These limitations not only affect the precision of the research results but also provide opportunities for improvement in future studies [2, 3].

6.2 Future Research Directions

Based on the identified limitations, future research on student behavior analysis in smart classrooms can proceed in several directions. First, the diversity and coverage of data sources should be further expanded. For example, cross-regional and cross-school collaborative research can be conducted to obtain more representative student behavior datasets. Additionally, by incorporating emerging technologies such as the Internet of Things (IoT) and blockchain, the level of automation in data collection and processing can be improved, thereby reducing the influence of human error on research results [3]. Second, at the technical level, future research should place greater emphasis on the application of multimodal data fusion analysis, particularly through in-depth exploration in areas such as affective computing and physiological signal monitoring. For instance, by combining audio, video, log, and physiological data, more comprehensive and accurate student behavior analysis models can be constructed, enabling dynamic monitoring and assessment of key indicators such as learning engagement and emotional states [11].

Moreover, future research could focus on the application of student behavior analysis in smart classrooms to educational equity and personalized instruction. For example, by examining differences in learning behaviors among diverse student groups, teachers can be provided with targeted instructional strategy recommendations, thereby promoting the equitable distribution of educational resources and improving overall learning outcomes. In addition, with the continuous development of AI technologies, future studies could experiment with advanced algorithms such as reinforcement learning and transfer learning to optimize the accuracy and robustness of behavior prediction models, thus providing a more scientific basis for educational decision-making [3]. Finally, more attention should be given to the ethical issues of student behavior analysis in smart classrooms, particularly in establishing stricter standards and regulations for data privacy protection and technology reliability, ensuring the legality and transparency of the research process [11]. These directions will not only help address current research shortcomings but will also provide important theoretical support and practical guidance for advancing the development of smart education.

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THE CONSTRUCTION OF DIGITAL GOVERNANCE ECOSYSTEM MODEL FOR DIGITAL TRANSFORMATION OF VOCATIONAL EDUCATION

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Abstract: Under the impact of the digital economy wave, the digital transformation of vocational education has become an inevitable trend of the times. However, the current problems such as technological fragmentation, low collaboration efficiency, and rigid data barriers have seriously hindered its development process. This study organically integrates ecological theory with the concept of digital governance, and constructs an innovative three-level progressive model of "Basic Support - Core Collaboration - Goal Achievement". Adopting a pyramid - shaped structure, this model effectively integrates multiple subjects and digital technology resources, and realizes the collaborative governance of the tripartite subjects (government, schools, and enterprises) with the help of four operating mechanisms. Focusing on solving the problem of "data silos", this model is committed to promoting in - depth sharing of industry - education data and facilitating the practical application of virtual training scenarios, thus providing a set of solutions with both theoretical depth and practical guiding significance for the digital transformation of vocational education.
Keywords: Vocational education; Digital transformation; Digital governance ecosystem; Model construction; Industry-Education integration; Tripartite collaboration

1 INTRODUCTION

Against the background of digital technology reshaping the industrial structure, the theory and practice of digital transformation in vocational education have become the focus of attention. From the perspective of technology empowerment, the iteration of emerging technologies such as artificial intelligence and big data has promoted the global industry towards digital and intelligent development. The digital economy has become the core driving force for economic growth, which puts forward higher requirements for the digital literacy, multi - scenario practical ability, and innovative thinking of technical and skilled talents. The digital transformation of vocational education directly affects the adaptation degree between talent supply and industrial demand [1].
From an international comparison perspective, Germany has built a digital training system with in - depth collaboration between enterprises and colleges relying on Industry 4.0, integrating technologies such as industrial Internet of Things into teaching to meet industrial needs. The United States has built a national digital resource sharing platform by virtue of the "National Vocational Education Technology Plan", forming a mechanism for resource integration and capacity co - construction, which provides a reference for China [2]. Looking back at China, although vocational education digitalization has achieved remarkable results in curriculum resource development and teaching model innovation, there are still structural contradictions in systematic governance, such as the superficial application of digital technology, the imperfect collaborative mechanism of multiple subjects, and the need to improve the unified digital governance ecosystem framework. In view of this, this study focuses on the theoretical construction of the digital governance ecosystem of vocational education, aiming to make up for the research limitations of focusing on technology application while neglecting ecosystem construction, provide an innovative path to solve the dilemmas such as governance fragmentation and imbalance between industry - education supply and demand, and contribute to the high - quality development of vocational education.

2 THEORETICAL BASIS

2.1 Connotation and Characteristics of Digital Transformation in Vocational Education

The digital transformation of vocational education is not a simple combination of technology and education, but a process of overall deconstruction and reconstruction of the vocational education system with digital technology as the core driving force. According to the theory of educational digital transformation, its essence is to use digital technology to break the limitations of time and space, optimize the allocation of educational resources driven by data, promote the transformation of vocational education from a supply - oriented model to a learner - centered one, and then cultivate high - quality technical and skilled talents suitable for the digital economy [1].
From an academic perspective, this transformation has four characteristics. First, systematicness and comprehensiveness, which covers the whole life cycle of curriculum development, teaching implementation, evaluation and feedback, and management services, and builds a closed - loop digital ecosystem. Second, innovation and

disruption, which rely on technologies such as VR and AI to give birth to new educational forms such as virtual simulation training and intelligent tutoring, and realize the innovation of teaching models. Third, dynamics and adaptability, which require continuous updating of teaching resources and talent training programs with the iteration of technology and industrial upgrading. Fourth, collaboration and openness, which emphasize that multiple subjects such as the government, colleges, and enterprises should break down boundaries and build a co - construction and co - governance digital governance pattern through data sharing and business collaboration [1].

2.2 Theories Related to Digital Governance Ecosystem

The digital governance ecosystem theory is the cross - product of ecosystem theory and digital governance theory. It decomposes the governance system into a three - dimensional coupled whole of subjects, technologies, and environment. Various elements achieve dynamic balance and collaborative evolution through material circulation, energy conversion, and information transmission. In the field of vocational education, the subject dimension is composed of the government, enterprises, colleges, teachers, and students to form an interactive network like a biological community [3]; the technology dimension is composed of big data, AI, blockchain, and other technologies to form technical infrastructure [4]; the environment dimension relies on policies and regulations, standards and norms, and social atmosphere to provide institutional guarantees and participation motivation. The practical essence of digital governance ecosystem in vocational education is to use digital technology to reconstruct governance processes, build a data - driven decision - making mechanism, break down barriers through data sharing, tap value through data analysis, and inject new impetus into the high - quality development of vocational education.

2.3 Interactive Relationship between Digital Transformation of Vocational Education and Digital Governance Ecosystem

The digital transformation of vocational education and the digital governance ecosystem present a collaborative evolution relationship of two - way empowerment, forming a spiral upward model through the coupling mechanism of technical support and institutional feedback. The digital transformation relies on new infrastructure such as intelligent teaching platforms and virtual training bases to build a technical carrier for multi - subject collaboration. At the same time, it promotes colleges and enterprises to break through the collaboration boundaries, reshape the relationship of rights, responsibilities, and interests, and expand the application field of the governance ecosystem. The digital governance ecosystem uses standardized systems and mechanism innovation to balance the interests of subjects, solve the transformation problems such as data barriers, and its dynamic adaptive characteristics are connected with technology iteration and industrial upgrading, providing sustainable momentum for the transformation [1].

3 CURRENT SITUATION AND PROBLEMS OF DIGITAL TRANSFORMATION IN VOCATIONAL EDUCATION

3.1 Current Situation of Digital Transformation in Vocational Education

The digital transformation of vocational education has achieved remarkable results in the field of infrastructure construction. By continuously promoting the transformation strategy, a three - dimensional and multi - level infrastructure support system has been built, which has laid a solid material foundation for the innovation of educational and teaching models [5]. From the perspective of network communication architecture, the vast majority of vocational colleges across the country have achieved full coverage of wired and wireless networks on campus. By deploying backbone networks, they ensure the stable operation of teaching applications with high bandwidth requirements such as high - definition video teaching and virtual simulation training, and avoid the impact of network problems on teaching effectiveness. In terms of hardware equipment configuration, intelligent interactive display terminals and teaching video recording systems have become standard teaching equipment in colleges, which can meet the daily needs of digital teaching. Some leading vocational colleges have further built new teaching spaces such as VR/AR immersive training laboratories and AI teaching quality diagnosis and analysis centers, creating innovative demonstration samples of digital teaching environments [6].

The digital construction of vocational education has also achieved remarkable results in the application of resources and technologies, promoting teaching innovation in multiple dimensions. At present, a three - level vocational education digital resource system (national, provincial, and college levels) has been formed, and a three - dimensional resource matrix centered on courseware development, virtual simulation experiments, industry typical case database construction, and assessment question bank design has been built to provide rich materials for teaching. Various vocational colleges actively develop school - based digital resources in combination with the needs of regional industrial development and their own professional characteristics. By introducing cutting - edge technologies such as virtual reality and artificial intelligence, they effectively break the limitations of traditional training equipment in time, space, and functions, and solve the problems in practical training [7]. At the same time, the online - offline hybrid teaching model is widely used. Most colleges deeply integrate digital resources into the curriculum teaching system, realizing the vertical deepening and horizontal expansion of teaching content, and significantly enhancing the pertinence and effectiveness of vocational education and teaching [8].

Under the in - depth penetration of digital technology, the teaching model of vocational education has undergone an all - round and systematic transformation, showing distinct digital characteristics. Relying on the empowerment of digital technology, the teaching model has achieved systematic innovation. In the field of complex practical operations, virtual simulation teaching has become an important teaching model due to its high simulation degree and strong interactivity. Digital twin technology provides support for the integration of theory and practice teaching, promoting the in - depth integration of theoretical knowledge and practical operations [9]. In addition, teaching methods such as project - based learning and inquiry - based learning are deeply combined with digital technology to build a new student - centered teaching system. Teachers can also use big data analysis technology to deeply analyze the characteristics of students' learning behaviors, establish personalized learning models, and accurately push learning tasks, thus effectively improving the targeting and effectiveness of teaching.

3.2 Problems Faced by the Digital Transformation of Vocational Education

3.2.1 Application of digital technology: coexistence of superficialization and fragmentation

Although digital technology has been integrated into vocational education, there are still obvious bottlenecks in the depth and breadth of application. In teaching practice, most teachers only use digital technology for superficial assistance such as PPT demonstrations and video playback, and there is insufficient in - depth application of cutting - edge technologies such as artificial intelligence learning situation analysis, big data teaching diagnosis, and virtual reality training. In the field of management, digital technology does not cover the whole life cycle of enrollment, teaching, and employment, and fails to form a closed - loop management system for data collection, analysis, decision - making, and feedback [10]. In addition, the application of technology is fragmented. The procurement of digital tools by various departments and majors lacks top - level coordination, resulting in prominent problems of repeated construction and resource mismatch, which restricts the overall improvement of teaching efficiency.

3.2.2 Digital literacy of teachers and students: disconnection between basic abilities and high - level needs

The structural shortage of digital literacy of teachers and students has become a core problem restricting the in - depth development of the digital transformation of vocational education. From the perspective of teachers, most teachers lack the ability in the development of virtual simulation courses, the integration of multi - modal resources, and the application of intelligent tools, making it difficult for them to design digital teaching projects that are deeply integrated into the real application scenarios of the industry. Some senior teachers have weak adaptability to digital technology and show a tendency of technology use anxiety. Their willingness to actively explore emerging digital technologies and their ability to transform them into practice in the process of professional development need to be improved. From the perspective of students, although the new generation of learners shows a high degree of proficiency in the operation of basic digital tools, there is an obvious ability gap in the high - level application fields of digital technology such as data modeling and analysis, algorithm thinking construction, and information security protection. This lack of ability directly limits their ability to independently carry out practical innovation projects based on industry big data. In addition, the management of colleges generally has the phenomenon of superficial use of digital governance tools, mainly applying them to basic functions such as data statistics, and failing to give full play to the core value of the data center in optimizing teaching decisions and intelligently allocating educational resources [11].

3.2.3 Digital governance mechanism: lack of standards and low collaboration efficiency

The lack of a standardized system is a key constraint factor in the construction of the digital governance system of vocational education. At present, there is no unified national technical standard and standard system, which leads to significant differences in the format coding and storage protocols of digital resources among vocational colleges. The interface compatibility between information system platforms is insufficient, which ultimately leads to data interaction barriers and the typical phenomenon of "data silos", hindering the interconnection of resources across colleges and regions. In the construction of the multi - collaborative governance mechanism, the division of rights and responsibilities among the government, enterprises, and vocational colleges lacks a clear institutional definition. Enterprises are cautious about the opening and sharing of production and operation data due to the protection of intellectual property rights and commercial competition, and the provision of core data to colleges is not ideal. Vocational colleges have obvious deficiencies in the construction of standardized collection, professional analysis, and feedback paths of talent training quality evaluation data, and fail to establish a standardized and efficient data transmission channel, resulting in the disconnection of data between the industry and education sectors. In addition, the construction of the data security governance system is obviously lagging behind. Most vocational colleges have not built a perfect framework for the classified and hierarchical management system of teaching data, and there are institutional gaps in key technical links such as sensitive information encryption and protection of teachers' and students' privacy. This leads to systematic security risks such as data leakage and abuse in business scenarios such as the collection of teachers' and students' personal information and the storage and management of teaching process data [12-13].

3.2.4 Digitalization of industry - education integration: superficial cooperation and resource disconnection

The endogenous driving force of enterprises to participate in the digital transformation of vocational education is obviously insufficient. At present, the school - enterprise cooperation model mostly stays at the superficial level of affairs such as equipment donation and internship base licensing. In the core fields such as the collaborative development of digital education resources and the joint design of talent training systems, the participation of enterprises and the investment of resources are insufficient [14]. From a deeper perspective, there is no perfect collaborative sharing mechanism for school - enterprise digital resources. The high - quality digital production resources accumulated by enterprises lack a transformation path suitable for teaching and are difficult to integrate into the classroom. However, the virtual simulation courses and digital teaching materials independently developed by colleges are often disconnected from the actual production scenarios of enterprises because they are not connected to the latest production processes and industry standards of enterprises, resulting in the limited practical value of these teaching resources in cultivating students' post - adaptation ability. The lack of synergy efficiency of industry - education resources directly leads to a structural mismatch between the digital skills training standards of vocational college graduates and the actual needs of the industry, forming an obvious talent supply gap and restricting the core role of the digital transformation of vocational education in serving industrial development.

4 CONSTRUCTION OF DIGITAL GOVERNANCE ECOSYSTEM MODEL FOR VOCATIONAL EDUCATION

4.1 Overall Structure of the Model

Based on the ecosystem theory and the digital governance theory framework, this study innovatively constructs a pyramid - shaped digital governance ecosystem model for vocational education, which includes three parts: basic support, core collaboration, and goal achievement. This model follows the logical closed - loop of technology empowering subjects, subjects co - constructing the environment, and the environment feeding back development.

The model systematically integrates three core components: the basic support layer, the core collaboration layer, and the goal achievement layer. The basic support layer is composed of digital infrastructure (hardware facilities and digital platforms) and an environmental guarantee system (policies and regulations, standards and norms), providing material foundations and institutional guarantees for the operation of the model. The core collaboration layer integrates multiple governance subjects such as government departments, industry enterprises, vocational colleges, teachers, and students, and combines digital governance tools such as big data analysis, artificial intelligence algorithms, and blockchain technology to maximize governance efficiency through collaborative linkage among subjects and technology empowerment. The goal achievement layer takes the cultivation of high - skilled talents who meet the development needs of the digital economy as the core goal, promotes the transformation and upgrading of vocational education towards intelligence, personalization, and precision, and realizes the in - depth coupling between the improvement of education quality and the demand for industrial talents. Relying on four operating mechanisms (collaborative cooperation mechanism, data circulation mechanism, incentive and constraint mechanism, and innovation and evolution mechanism), the model builds a dynamically balanced ecosystem, aiming to solve the practical dilemmas such as governance fragmentation and the mismatch between industry - education supply and demand in the process of digital transformation of vocational education.

4.2 Model Structure Design: Pyramid - shaped Hierarchical Structure

4.2.1 Bottom layer: the basic support layer lays a solid foundation for the operation of the ecosystem

The basic support layer is the hardware base and institutional guarantee for the operation of the model, which mainly covers two core dimensions: the construction of digital infrastructure and the construction of environmental guarantee elements. In terms of digital infrastructure, by building hardware such as campus 10 - gigabit backbone networks, deploying intelligent interactive terminals, and constructing virtual simulation laboratories, a unified cloud computing platform and Internet of Things environment are built simultaneously to realize the real - time transmission and storage of teaching and training data. At the same time, relying on the data center, it provides full - process technical support for data collection, processing, analysis, and application, forming a closed - loop system. In the construction of environmental guarantee elements, a institutional framework is formulated with policies and regulations, standards and norms as the core. Policies and regulations are improved to clarify the boundaries of rights and responsibilities and behavioral norms of various subjects in the ecosystem. The standard and normative system is improved to ensure the standardized operation and interconnection of various components, laying a solid institutional foundation for the stable operation of the digital governance ecosystem model of vocational education.

4.2.2 Middle layer: the core collaboration layer builds a multi - linkage pattern

The core collaboration layer is the core driving mechanism for the operation of the model. It builds a systematic collaborative governance structure through the in - depth integration of multiple governance subjects and digital technology systems. In terms of multi - subject collaboration, a governance system with clear rights and responsibilities is formed. The government is responsible for policy planning, resource allocation, and performance evaluation. Enterprises undertake technology supply, industrial demand transmission, and practical resource construction. Colleges focus on the construction of teaching systems, curriculum development, and talent training. Teachers carry out digital teaching innovation and student guidance. Students complete the internalization of knowledge and skills through independent learning and practice. In terms of the digital technology empowerment path, big data analysis is used to carry out learning situation diagnosis, teaching evaluation, and talent demand forecasting. Artificial intelligence is used to develop intelligent teaching assistance systems and personalized learning platforms. Blockchain is used to build a trusted data certification and sharing mechanism. Virtual reality is used to create high - simulation training environments. At the same time, through the construction of cross - departmental data centers, the integration and sharing of multi - source heterogeneous data are realized, and the information barriers among subjects are broken.

4.2.3 Top layer: the goal achievement layer focuses on the core of talent training

The goal achievement layer is the value - oriented dimension of the model operation, and its core goal system covers two key aspects: talent training and education innovation. The talent training dimension focuses on cultivating compound high - skilled talents who have both professional theories, practical skills, and data thinking, algorithm application capabilities, and information security awareness. By connecting with the talent needs of core industries in the digital economy such as intelligent manufacturing and artificial intelligence, a precise education mechanism for industry - education collaboration is built. The education innovation dimension relies on the collaborative linkage between the underlying facilities and the middle - layer subjects to promote the implementation of innovative application scenarios such as the construction of virtual simulation teaching environments, real - time sharing of industry - education data, the construction of intelligent teaching evaluation, and the planning of AI personalized learning paths. It drives the transformation of vocational education from the traditional model to an intelligent,personalized, and precise model, and finally achieves the dual goals of comprehensively improving vocational education quality and dynamically adapting to industrial talent needs.

4.3 Model Element Composition: A Tripartite Ecosystem

4.3.1 Subject elements: multi - collaborative governance participants

Subject elements are the core actors in the digital governance ecosystem, consisting of five types of subjects: the government, enterprises, vocational colleges, teachers, and students. Each subject has a clear functional positioning and close interactive connections in the ecosystem. The government undertakes the functions of policy formulation, resource coordination, and supervision and evaluation. It regulates the operation of the system by issuing special policies for digital transformation, building a financial support system, and establishing a multi - dimensional evaluation index system. At the same time, as an organizer of cross - departmental and cross - regional coordination mechanisms, it is responsible for coordinating the interests of multiple subjects and promoting the collaborative development of the ecosystem. Enterprises assume important roles in technology empowerment, demand transmission, and practical support. Relying on their industrial advantages, they provide real industrial demand data and production scenario resources for the ecosystem, deeply participate in curriculum development and training base construction, and build an industry - education integration practice platform. By accepting students for internships and employment, they establish a talent quality feedback mechanism to provide a basis for optimizing talent training programs. Vocational colleges, as the main positions for talent training, focus on the construction of talent training systems, curriculum resource development, and teaching model innovation. They build intelligent teaching platforms, develop school - based digital resource libraries, implement mixed teaching and virtual simulation training, and establish a dynamic adjustment mechanism to ensure the accurate connection between talent training and industrial needs. Teachers assume key responsibilities in teaching implementation, resource integration, and learning guidance in the teaching process. They design project - based digital teaching plans, use intelligent teaching tools to carry out differentiated teaching, organize students to conduct digital skill practices, and optimize teaching strategies based on teaching practice feedback. As the terminal output subject of the ecosystem, students complete the acquisition of knowledge, improvement of skills, and transformation of abilities through participating in digital learning and practical projects. They feedback learning needs and experiences to form a positive cycle of teaching and learning, and eventually grow into high - quality skilled talents who adapt to the development of the digital economy.

4.3.2 Technical elements: core driving force for ecosystem operation

Technical elements are the core link connecting subjects and the environment in the vocational education digital governance ecosystem. Their essence is to realize the reconstruction of governance processes and the innovation of collaborative mechanisms through digital technology empowerment. The system includes seven core technology groups. Big data technology completes the collection, storage, and mining of multi - source heterogeneous data relying on the ETL (Extract, Transform, Load) process, and provides data support for governance decisions through data modeling and visual analysis. Artificial intelligence technology builds an intelligent decision - support system based on machine learning and natural language processing to realize risk early warning, trend prediction, and decision - making deduction. Cloud computing technology builds a dynamically scalable computing resource pool with a distributed architecture and virtualization technology to ensure the efficient and stable operation of the governance platform. Internet of Things technology realizes the interconnection between the physical space and the digital space according to the M2M (Machine - to - Machine) protocol, and builds a governance scenario with real - time perception and intelligent response. Blockchain technology builds a trusted data sharing and collaborative governance mechanism through distributed ledgers, consensus mechanisms, and asymmetric encryption algorithms. 5G technology supports the real - time transmission of governance data and edge computing with its high - bandwidth, low - latency, and wide - connection characteristics. Digital twin technology realizes the digital mapping and dynamic optimization of governance processes with the help of multi - physical field modeling and simulation optimization technology.

4.3.3 Environmental elements: guarantee for the stable operation of the ecosystem

Environmental elements are the core support of the vocational education digital governance ecosystem, and a institutional guarantee system and cultural ecosystem need to be constructed from three dimensions: policies and regulations, standards and norms, and social culture. In the dimension of policies and regulations, the government plans the transformation path by issuing special policy documents such as the "Vocational Education Digital Transformation Action Plan" and provides institutional guarantees for data security by formulating regulations such as the "Vocational

College Teaching Data Protection Regulations". In the dimension of standards and norms, the national unified digital standard system clarifies norms from aspects such as resource management, technology application, and process optimization, eliminates data barriers, and realizes the interconnection and collaborative sharing of educational resources across platforms. In the dimension of social culture, relying on multiple channels such as media communication matrices and academic discussion platforms, the public's awareness of the digital transformation of vocational education is continuously deepened. Through building practical innovation platforms to display digital achievements, a cultural ecosystem that values digital literacy cultivation and encourages collaborative innovation is cultivated, providing a sustainable social and cultural foundation for the digital transformation of vocational education.

4.4 Operation Mechanism: A Dynamically Collaborative Ecosystem Driving System

4.4.1 Collaborative cooperation mechanism: building a multi - subject co - governance pattern

With the core concept of "benefit sharing and responsibility sharing", a tripartite collaborative governance alliance structure of "government - enterprise - college" is constructed, and the specific implementation is carried out through the following paths. Promote the construction of a substantive collaborative platform, build an industry - education integration council governance system composed of government education authorities, representatives of leading enterprises in the industry, and heads of key vocational colleges, establish a quarterly joint meeting system, promote the joint construction and sharing of digital education resources, and the collaborative construction of training bases. At the same time, set up a school - enterprise special workshop to jointly develop digital talent training programs in key professional fields to solve the structural contradiction between the curriculum system and industrial needs. Construct a rights, responsibilities, and interests distribution mechanism, clarify the rights and responsibilities boundaries of the government, enterprises, and colleges through multi-party cooperation agreements, and establish a multi - dimensional benefit sharing mechanism at the same time.

4.4.2 Data flow and sharing mechanism: realizing two - way connection of industry - education data

Relying on a unified data center and blockchain technology, a full - process data governance system of "collection - cleaning - sharing - application" is constructed. In terms of data collection and standardization, the "Vocational Education Data Collection Specification" is formulated to clarify the scope of data collection for college teaching and enterprise industry. Multi - source heterogeneous data is intelligently collected through the data center, and data quality is guaranteed through the processing of cleaning algorithms and desensitization technology. In terms of data security sharing mechanism, an industry - education integration alliance chain is built based on blockchain, and the mode of "data on - chain without desensitization and authorized use with traceability" is adopted to open non - core production data. A data classification and grading system (public level, internal level, and confidential level) is established, and supporting access control strategies are matched to strengthen security protection. In terms of data application and closed - loop optimization, a big data platform is used to analyze talent training and industrial demand data, providing a basis for enterprises to optimize post standards and colleges to adjust professional courses, and forming a "data - driven - dynamic optimization" governance closed loop.

4.4.3 Incentive and constraint mechanism: stimulating the participation motivation of ecosystem subjects

A dual collaborative governance mechanism of "positive incentive - bottom - line constraint" is constructed, and institutional design is used to guide multiple subjects to participate in compliance and empower actively. In terms of the incentive mechanism, the government sets up a special financial incentive fund for the digital transformation of vocational education, and implements differentiated subsidies for core fields such as the construction of virtual simulation training bases in vocational colleges. A tax preferential system for enterprises to participate in school - enterprise cooperation is established, and the digital participation of enterprises is included in the selection and evaluation indicators of government projects. Colleges build a teacher development evaluation system oriented to digital capabilities, include digital teaching design in professional title evaluation, establish an incentive mechanism based on digital skill output, give performance bonuses to excellent teachers, and set up a stepped digital skill scholarship at the same time, stimulating students' motivation through systems such as credit replacement. In terms of the constraint mechanism design, an independent third-party evaluation system is constructed, an evaluation index matrix is established from three dimensions including policy implementation validity, dynamic assessment and closed - loop management are implemented; the "Vocational Education Digital Governance Compliance Operation Guide" is formulated, a negative behavior list is established, and a hierarchical punishment mechanism including risk early warning and interview rectification is constructed for violations such as delayed data sharing to ensure the orderly operation of the ecosystem.

4.4.4 Innovation and development mechanism: promoting the iterative upgrading of the ecosystem

A three - stage evolution mechanism of "pilot - promotion - iteration" is constructed to realize the coordinated development of the vocational education digital governance ecosystem and the digital economy. In the pilot exploration stage, through the joint selection of school - enterprise cooperation units with good digital foundations by the government and industry associations, innovative practices such as the construction of meta - universe training scenarios, the development of AI intelligent evaluation systems, and the construction of digital twin industry - education integration platforms are carried out. In the achievement transformation stage, relying on the vocational education digital innovation achievement evaluation mechanism, scientific methods such as the Delphi method are used to evaluate the effectiveness and universality of the project, transform mature experience into industry standards and norms, and realize the promotion of achievements through the construction of case libraries, special training, and digital resource platforms. In the dynamic optimization stage, a monitoring index system covering dimensions such as technology adaptability and industrial demand response is constructed. Based on the dynamic evaluation results of the ecosystem, policy standards and resource allocation plans are revised regularly, and the continuous evolution of the ecosystem is promoted through annual academic seminars to ensure that the digital governance ecosystem maintains dynamic adaptation to industrial changes.

4.5 Governance Implementation Path: A Three - dimensional Driven Implementation Framework

Based on the theoretical framework of "policy incentive - technology drive - subject linkage", a three - dimensional collaborative governance system of government, enterprises, and colleges is constructed. At the institutional level, the phased construction goals are clarified through the "Guiding Opinions on the Construction of the Vocational Education Digital Governance Ecosystem", a three - level (ministry - province - college) collaborative mechanism is established, and a third-party evaluation system is introduced to carry out dynamic monitoring. In the dimension of industry - education integration, a virtual simulation training platform is jointly built relying on enterprise data resources, a "dual tutor system" teaching model is implemented, and a talent training quality feedback mechanism is established. In terms of the college implementation path, a data center is built to realize the digital integration of teaching resources, special training on teachers' digital literacy is carried out, a diversified teaching quality evaluation system including digital skill evaluation indicators is constructed, and finally a digital governance ecosystem with multi - subject collaboration and efficient allocation of elements and resources is formed.

5 INNOVATIVE VALUE AND APPLICATION VALUE OF THE DIGITAL GOVERNANCE ECOSYSTEM MODEL

5.1 Innovative Value

This study breaks through the limitations of the "technology - oriented" research paradigm in the traditional digital transformation of vocational education. Based on the cross - perspective of ecosystem theory and digital governance theory, it constructs a tripartite collaborative analysis framework of "subject - technology - environment". By deconstructing the action mechanism and functional boundaries of each element, it innovatively proposes a theoretical construction model of the vocational education digital governance ecosystem, filling the research gap in related fields. At the practical level, the study constructs a pyramid - shaped hierarchical governance structure. Relying on four operating mechanisms (collaborative governance, data sharing, incentive and constraint, and dynamic evolution), it effectively solves practical problems such as weak government leadership, unbalanced school - enterprise collaboration, and slow system iteration under the traditional governance model. Among them, the application of blockchain technology breaks the trust barrier of cross - subject data sharing, and the innovative design of the dynamic evolution mechanism endows the system with adaptive capabilities to adapt to technological innovation and industrial upgrading.

5.2 Application Value

In the process of solving the practical problems of transformation and promoting the implementation of relevant work, it is necessary to solve the key pain points in a targeted manner. In terms of technology integration, relying on the unified standards of the basic support layer, scattered digital resources are integrated to realize "one data center, multi - end reuse". In terms of deepening industry - education integration, enterprises are promoted to participate in depth with the help of collaboration and data sharing mechanisms. When improving digital literacy, the digital teaching ability of teachers and the high - level digital skills of students are significantly enhanced through training and incentive mechanisms. At the same time, it is necessary to provide a replicable practical path for the implementation of the transformation. The model adopts the path of "policy incentive - technology drive - subject linkage", which has strong operability and replicability. Provincial governments can use this to build regional data centers, enterprises can share data relying on the alliance chain, and colleges can promote teaching reform. In addition, the model also takes supporting industrial development and helping the cultivation of digital economy talents as its goals. Through the interconnection of industry - education data and the implementation of virtual training, it accurately meets industrial needs. Colleges can adjust courses according to the real - time needs of enterprises, cultivate compound talents, and effectively alleviate the industrial skill gap.

6 CONCLUSION AND OUTLOOK

This study addresses the governance challenges in the digital transformation of vocational education and constructs a pyramid - shaped digital governance ecosystem model consisting of basic support, core collaboration, and goal achievement. The research shows that the current digitalization of vocational education has shortcomings in technology application, subject collaboration, and governance mechanisms. However, this model realizes the innovation of the governance paradigm by integrating subject, technology, and environment elements and four operating mechanisms, and has both theoretical and practical value. Future research can expand the pilot scope of the model, verify its adaptability in different scenarios and optimize it; explore the integrated application of cutting - edge technologies such as the meta - universe and generative AI with the model; strengthen the empowerment mechanism for disadvantaged subjects, such as improving incentive policies and support measures; improve data security standards in accordance with relevant laws, and use technologies such as privacy computing to improve the efficiency of data circulation, so as to promote the optimization of the digital governance ecosystem.

COMPETING INTERESTS

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IMPLEMENTATION DIFFICULTIES AND QUALITY-EFFICIENCY IMPROVEMENT STRATEGIES OF AFTER-SCHOOL SERVICES UNDER THE "DOUBLE REDUCTION" POLICY

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Abstract: This paper presents a comprehensive analysis of the implementation challenges facing after-school services under China's "Double Reduction" policy, with a specific focus on issues related to teaching staff, curriculum design, and resource allocation. It identifies key obstacles such as teacher shortages, lack of diverse and engaging curricula, and insufficient educational resources, which collectively hinder the effectiveness of these services. In response, the study puts forward a series of practical strategies aimed at enhancing the quality and efficiency of after-school provision. These include optimizing the structure and capacity of the teaching workforce through professional development and flexible recruitment, innovating the curriculum system to incorporate interdisciplinary and interest-oriented learning activities, and improving the integration and expansion of resources via digital platforms and community partnerships. The proposed measures are designed to not only address current operational difficulties but also to promote the sustainable and high-quality development of school-based after-school services. Ultimately, this research seeks to support the broader goals of the "Double Reduction" policy in reducing academic burdens and strengthening holistic education, thereby creating a more supportive and enriching environment for students' growth.
Keywords: Double reduction policy; After-school services; Difficulties; Improvement strategies

1 INTRODUCTION

In the sweeping wave of educational reform, China's "Double Reduction" policy has made a significant and timely debut. Introduced in 2021, this landmark initiative aims to fundamentally transform the educational landscape by alleviating the excessive academic burden imposed on students in compulsory education—specifically by reducing heavy homework assignments and curtailing off-campus tutoring. The policy embodies a clear and profound vision: to allow education to return to its original essence, emphasizing holistic development over mere test scores, and fostering a healthier, more balanced learning environment.

As a crucial supporting mechanism of the "Double Reduction" policy, school-based after-school services function as an essential bridge between formal schooling and students' personal growth. These services create a dedicated, structured, and supportive space where students can engage in meaningful academic reinforcement, explore diverse interest-based activities, and develop social and practical skills beyond the regular classroom hours. By extending the school day in a constructive manner, after-school programs play a pivotal role in enriching students' educational experiences, supporting their intellectual and creative curiosity, and strengthening their physical and emotional well-being.

The significance of these services extends beyond the students themselves—they also provide tangible assistance to parents. By offering a safe, supervised, and enriching environment after normal school hours, after-school services help resolve practical challenges faced by many families, particularly working parents who struggle to pick up their children at the end of the conventional school day. This not case only enhances parental peace of mind but also reduces the economic pressure and time constraints associated with private tutoring or alternative childcare arrangements.

However, the implementation of after-school services is fraught with real-world challenges and complexities. One major issue is the shortage of qualified and sustainable teaching staff. Many teachers, already burdened with heavy instructional responsibilities during the school day, experience fatigue and decreased motivation when tasked with additional after-school duties. This has led to concerns over teaching quality and continuity. Furthermore, there is an over-reliance on existing school faculty without sufficient diversification of instructors, such as involving professional community experts or external partners.

Another critical challenge lies in curriculum design and content delivery. Many after-school programs tend to prioritize academic remediation or homework supervision, often at the expense of more innovative and interest-driven activities. While academic support is important, an overemphasis on formal instruction risks replicating the very pressures the "Double Reduction" policy seeks to mitigate. There is a pressing need to introduce more varied, stimulating, and holistic learning experiences—such as STEM projects, arts, sports, mental health education, and community service—that truly contribute to students' all-around development.

Resource availability and integration also pose significant obstacles. Schools, especially those in rural or economically disadvantaged regions, frequently encounter difficulties in securing adequate funding, facilities, and educational materials to run high-quality after-school programs. The imbalance in resource distribution exacerbates educational inequality, as students in better-resourced urban schools enjoy more opportunities than their peers in underserved areas. Additionally, the effective integration of digital tools and community resources remains underdeveloped, limiting the potential for innovative and scalable solutions.

Given these multifaceted challenges, improving the quality and effectiveness of after-school services has become an urgent priority. There is a growing consensus that systemic measures are required—including optimizing teacher allocation through specialized recruitment and incentives; enriching the curriculum with modular, student-centered activities; and enhancing public-private partnerships to mobilize additional resources. Such efforts are essential to ensure that after-school services fulfill their intended role as a catalyst for educational equity, student well-being, and sustainable development[1-3].

2 IMPLEMENTATION DIFFICULTIES OF AFTER-SCHOOL SERVICES UNDER THE "DOUBLE REDUCTION" POLICY

2.1 Insufficient Number of Professional Teachers

The courses involved in after-school services are rich and varied, covering many fields such as arts, sports, and technology. However, looking at the current staffing situation in schools, the number of professional teachers falls far short of the demand. Taking programming courses as an example, many schools simply lack professional programming teachers. When offering after-school programming services, they often have to temporarily pull in teachers from other subjects to "fill the gap." But as these teachers are not specialists, they often struggle to explain programming knowledge thoroughly during teaching[4]. Consequently, the teaching effectiveness is greatly reduced, and students end up with only a partial understanding.

2.2 Limited Teacher Energy

Teachers already undertake heavy daily teaching tasks. Now, with the addition of after-school services, their working hours have been significantly extended. Working non-stop from morning till night depletes their energy considerably. Over time, teachers inevitably feel exhausted. In this state, maintaining full enthusiasm and high concentration during after-school services becomes quite difficult. Many teachers helplessly express that with such long working hours daily, they feel a bit "low on battery" by the time after-school services come around[5], finding it hard to guide students with the same vitality they had at the start of the school day.

2.3 Lack of Distinctive Features in Curriculum Design

Observing after-school service classes in some schools reveals a common phenomenon: the curriculum predominantly consists of homework guidance. This monotonous curriculum model lacks novelty and struggles to attract students' attention. Schools fail to fully leverage their own unique characteristics and students' interests, resulting in courses that cannot meet students' diverse developmental needs. In some schools, after-school services almost always involve students doing homework independently with teachers available for questions. The whole process is dull and tedious, failing to boost student participation enthusiasm. Many students even perceive after-school services as another segment of their "learning hardship."

2.4 Untimely Curriculum Updates

While the era is rapidly developing and students' needs are constantly changing, after-school service curricula should ideally keep pace with the times. However, the reality is that the curricula in some schools seem "frozen," remaining unchanged for long periods with outdated content[6]. For instance, consider handicraft courses: in some schools, the content hasn't been updated for several years. While students might find it novel initially, they lose interest over time, feeling listless and finding it tedious during each session.

2.5 Limited Funding Investment

Implementing after-school services requires expenditure in all aspects: hiring professional teachers costs money, purchasing teaching materials costs money, and maintaining venues and facilities involves significant expenses. However, the financial situation of some schools is not optimistic; limited funds simply cannot provide solid support for after-school services. For example, some schools wanting to offer technology-related after-school service courses need to purchase advanced technological equipment[7]. But due to funding shortages, they have to hold back, and students miss the opportunity to engage with cutting-edge technological knowledge.

2.6 Inadequate Venues and Facilities

After-school services require various venues and facilities for support, such as laboratories, gymnasiums, and art classrooms. However, some schools, due to limited space and aging, outdated facilities, greatly restrict the conduct of after-school service activities. Taking dance after-school services as an example, some older schools lack dedicated dance studios. Students can only have classes in regular classrooms, which are not only cramped but also lack professional dance facilities. Students cannot move freely, and naturally, the learning outcomes are not optimal.

3 STRATEGIES FOR IMPROVING THE QUALITY AND EFFICIENCY OF AFTER-SCHOOL SERVICES UNDER THE "DOUBLE REDUCTION" POLICY

3.1 Strengthen In-Service Teacher Training

Schools should prioritize enhancing the professional capabilities of their in-service teachers by regularly organizing various professional training sessions. This is particularly important in fields closely related to after-school services, such as arts, sports, and technology, where training efforts should be intensified. For example, senior teachers from art colleges could be invited to the school to provide professional training in areas like painting and music for the teachers. Through such training, teachers can acquire more professional teaching methods and skills. Returning to the classroom, they will be better equipped to handle the teaching demands of after-school service courses, providing students with a more enriching classroom experience.

3.2 Introduce External Professional Talent

Besides tapping into the potential of in-school teachers, external professional talent can be actively brought in to participate in after-school services. Figures like folk artists and professional coaches possess rich practical experience and superb professional skills in their respective fields[8]. Taking paper-cutting courses as an example, a school could hire a locally renowned paper-cutting artist to conduct a weekly after-school service class. These folk artists can teach students paper-cutting techniques hands-on, allowing students to experience the charm of traditional culture up close. This offers students an experience distinctly different from teaching by in-school teachers, enriching their learning journey.

3.3 Develop Characteristic Courses

Schools should fully leverage their cultural advantages and combine them with students' interests and hobbies to create distinctive after-school service courses unique to the school. For instance, schools with a profound traditional cultural heritage could establish characteristic courses like calligraphy or opera. Through these characteristic courses, students can gain an in-depth understanding of traditional culture, foster a sense of identity with it, and simultaneously discover their own unique interests, finding their own development direction.

3.4 Dynamically Update Course Content

Schools need to establish a dynamic evaluation and update mechanism for course content, regularly collecting student feedback and keeping pace with the times. With the rise of artificial intelligence technology, schools can seize the opportunity/respond accordingly and timely add basic AI knowledge to technology-related courses. This way, the course content consistently maintains freshness and practicality can continuously attract students' attention and stimulate their learning enthusiasm.

3.5 Seek Financial Support

Schools should proactively communicate with government departments to strive for more financial support, providing sufficient funding guarantees for after-school services. The government could also specifically establish special funds for after-school services. These funds could be used to improve teaching facilities, purchase advanced teaching equipment, and also to hire better teachers, thereby enhancing the quality of after-school services from both hardware and software perspectives.

3.6 Integrate Social Resources

There are actually many rich social resources that can be utilized for after-school services. Schools need to be adept at integrating these resources. For example, schools can establish cooperative relationships with nearby science museums, regularly organizing students to conduct scientific practice activities there. In the science museum, students canengage with the latest scientific and technological achievements, personally experience various tech projects, broaden their horizons, and enrich their knowledge reserve.

4 CONCLUSION

Under the "Double Reduction" policy, after-school services hold significant importance for student growth and the development of the entire education sector. Although current after-school services indeed face a series of difficulties during implementation, such as teacher shortages, monotonous curriculum content, and insufficient resource investment, there are always more solutions than difficulties. As long as we start by optimizing the teaching workforce, enriching the curriculum system, and increasing resource investment, and implement various strategies step by step, we will certainly be able to effectively enhance the quality and efficiency of after-school services. Let after-school services truly become a joyful paradise for students to thrive, a solid reliance for parents to feel assured and secure, thereby promoting the development of education in a more positive and healthy direction.

COMPETING INTERESTS

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THE ROLE OF ARTIFICIAL INTELLIGENCE IN PROMOTING THE DEVELOPMENT OF HEALTH ASSESSMENT TRAINING TEACHING

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Abstract: This paper explores the application and development trends of artificial intelligence (AI) technology in health assessment practical training education. By analyzing current challenges in this field, it highlights AI's advantages in data processing, simulation, and personalized instruction. Through detailed case studies, the paper examines specific implementation models and proposes effective strategies to deepen AI integration with health assessment training. Research demonstrates that AI not only significantly enhances teaching efficiency and quality but also provides robust support for cultivating high-caliber health assessment professionals. These advancements carry profound implications for advancing the modernization of health assessment training systems.
Keywords: Artificial intelligence; Health assessment; Practical training teaching; Teaching mode; Talent training

1 INTRODUCTION

Health assessment is a core course in nursing education, with its practical training designed to cultivate students 'ability to apply professional knowledge and skills in accurately evaluating individual or group health conditions. As societal demand for health services continues to grow, the standards for health assessment professionals are also rising. However, traditional practical teaching models face challenges such as limited resources, monotonous scenarios, and difficulties in meeting personalized learning needs. The rapid development of artificial intelligence technologies—including machine learning, natural language processing, and virtual reality—has brought new opportunities and challenges to health assessment training, while also providing significant potential for AI applications in smart education [1]. Integrating AI into health assessment training not only innovates teaching methods but also significantly enhances instructional effectiveness, stimulates students' interest and creativity [2], and better aligns with the high standards required for cultivating health assessment professionals in the new era. Therefore, exploring how AI can support the advancement of health assessment training holds both theoretical and practical significance.

2 CURRENT PROBLEMS IN HEALTH ASSESSMENT TRAINING TEACHING

2.1 Insufficient Teaching Resources

In traditional health assessment training programs, teaching resources are often constrained by time and space limitations. For instance, the scarcity of authentic clinical case studies leaves students with limited access to diverse medical scenarios, forcing them to rely on limited textbooks and simulated cases. This significantly hampers their practical skills development and clinical decision-making abilities. Moreover, the quantity and variety of training equipment restrict both the scale and effectiveness of instruction. Many institutions use outdated equipment that fails to meet modern healthcare demands, particularly the lack of advanced devices like the latest electrocardiogram machines and ultrasound diagnostic systems. This gap prevents students from mastering cutting-edge medical technologies and tools essential for contemporary practice.

2.2 Single Practice Scenario

Current clinical training is predominantly confined to simulated wards and laboratory settings. While these facilities provide basic operational practice, they often lack the complex variables present in real hospital environments. Students operating within such static scenarios miss crucial opportunities to develop critical competencies in authentic settings – including patient assessments across diverse cultural backgrounds, emergency medical interventions, and multidisciplinary team coordination. The rigidity of training environments hinders students' ability to apply theoretical knowledge flexibly. When confronted with unexpected emergencies or complex medical situations, they frequently feel overwhelmed, lacking the capacity for independent analysis and problem-solving. These limitations may hinder their ability to adapt swiftly to evolving professional challenges, ultimately impacting their career development and professional growth.

2.3 It is Difficult to Achieve Personalized Teaching

Given the significant differences among students in learning abilities, knowledge foundations, interests, and learning styles, traditional uniform teaching models struggle to meet each student's personalized learning needs. Teachers often find it challenging to comprehensively monitor every student's academic progress, comprehension levels, and weak areas during instruction, making timely targeted guidance and support difficult. This not only restricts students 'individual development but also hinders the full realization of their potential and overall skill enhancement. For instance, some students may excel in mathematics but struggle with language arts, while others might show great enthusiasm for science experiments yet lack interest in theoretical studies. Such diverse learning characteristics require educational systems to flexibly adjust teaching strategies to accommodate different student needs. However, traditional classrooms typically adopt a "one-size-fits-all" approach, leaving some students feeling either under-challenged or overwhelmed by overly simplistic content, which negatively impacts their motivation and learning outcomes. Therefore, implementing personalized teaching methods—such as differentiated instruction, project-based learning, and online resources—can better satisfy students' varied needs and promote their holistic development.

3 ADVANTAGES OF ARTIFICIAL INTELLIGENCE IN HEALTH ASSESSMENT TRAINING TEACHING

3.1 Powerful Data Processing Capability

Artificial intelligence (AI) technology possesses robust data processing and analytical capabilities. By integrating and analyzing vast amounts of health assessment data—including detailed medical records, comprehensive examination reports, and high-resolution imaging data—it can uncover underlying patterns and characteristics within the data. These analytical findings provide rich case resources for education, helping students understand key points in health assessment and diagnostic approaches for various diseases, such as early symptoms of heart disease and imaging features of cancer. Through deep learning, AI powered by artificial neural networks can efficiently evaluate and predict massive CT/MRI image datasets with high accuracy, significantly improving the precision and efficiency of medical diagnoses [3]. Additionally, AI enables real-time monitoring and analysis of students' learning data, including study duration, exam performance, and operational proficiency. This provides teachers with insights to adjust instructional strategies, thereby achieving personalized teaching and enhancing learning efficiency.

3.2 Simulation Capability

Artificial intelligence technologies such as virtual reality (VR) and augmented reality (AR) can create highly realistic simulation training scenarios [4]. AI combines virtual simulation technology (such as VR/AR) to build immersive practice scenarios, reducing the training threshold for high-risk or high-cost skills in higher vocational education [5]. Students can conduct health assessment practice operations in virtual environments, simulating real clinical work settings like emergency rooms, wards, and community health centers. These virtual environments not only replicate the layout and equipment of actual medical facilities but also incorporate various complex cases and emergencies, including cardiac arrest in emergency rooms, chronic disease management in wards, and preventive healthcare consultations in community health centers. This simulation not only exposes students to diverse case types and complex scenarios but also avoids risks associated with operating on real patients. Additionally, students can repeatedly practice until they master health assessment skills and enhance their practical operational abilities. Through immersive experiences, students can better understand disease progression processes, improving emergency response capabilities and decision-making proficiency.

3.3 Personalized Teaching Support

Artificial intelligence utilizes advanced machine learning algorithms to create personalized learning plans tailored to each student's unique characteristics and progress.The application of AI data mining technology to identify students' learning disabilities in higher vocational education, providing teachers with intervention basis [6]. For example, slower learners receive more detailed foundational video tutorials with interactive exercises to reinforce their knowledge, while high-achievers are challenged with complex case studies and advanced discussions to stimulate critical thinking. The intelligent tutoring system also features real-time Q&A capabilities that promptly address students' queries, ensuring every learner receives customized educational support. Through deep analysis of student data, AI provides teachers with instant, precise feedback [7]. This mechanism not only helps educators accurately assess student performance but also enables timely adjustments to teaching strategies [8], fostering collaboration and resource sharing among educators to enhance overall instructional effectiveness.

4 APPLICATION CASES OF ARTIFICIAL INTELLIGENCE IN HEALTH ASSESSMENT TRAINING TEACHING

4.1 Application of Intelligent Health Assessment Simulation System

The intelligent health assessment simulation system has been introduced for practical training. Leveraging AI technology, this system can simulate patients of various ages, genders, and medical conditions, including children, elderly individuals, both genders, and those with chronic diseases such as hypertension, diabetes, and heart disease.

Through interactions with virtual patients, students complete health assessment procedures including medical history collection, physical examinations, and analysis of auxiliary test results. The system provides real-time scoring based on student responses and delivers detailed feedback with guidance. For example, when students omit critical information like family medical history or allergy records during history-taking, the system highlights key points and offers supplementation suggestions. When performing physical examinations with improper techniques—such as incorrect stethoscope usage or erroneous palpation methods—the system demonstrates correct procedures with video demonstrations. Additionally, the system features a personalized learning path that adjusts training content according to individual performance, ensuring targeted improvement for each student. By utilizing this system, students have significantly enhanced their health assessment skills, improved the accuracy and standardization of their practical operations, and strengthened their ability to handle various clinical scenarios.

4.2 Learning Analysis System Based on Artificial Intelligence

Develop an AI-powered learning analytics system that systematically collects student data during practical training, including classroom performance, online learning behaviors, lab reports, interactive engagement, and post-class assignment completion. Through data analysis, the system creates personalized learning profiles that clearly highlight students 'strengths and weaknesses. Teachers can then adjust teaching content and methods based on these insights to provide tailored recommendations. For instance, students struggling with cardiovascular health assessments may receive additional group tutoring and targeted exercises, enhanced with multimedia resources and simulated case studies, which effectively boosts learning outcomes and motivation. Additionally, the system identifies students' interests and learning styles to optimize teaching strategies, ensuring every learner achieves optimal learning experiences.

5 STRATEGIES TO PROMOTE THE DEEP INTEGRATION OF ARTIFICIAL INTELLIGENCE AND HEALTH ASSESSMENT TRAINING TEACHING

5.1 Strengthening Teacher Training

Teachers, as organizers and guides in educational activities, directly influence teaching effectiveness through their mastery of artificial intelligence (AI) technologies. Schools should regularly organize AI training courses and seminars to enhance teachers 'ability to utilize AI in instruction. Training content may include foundational AI theories, practical applications of common teaching software and platforms, and development of intelligent educational resources. Additionally, schools should encourage teachers to conduct teaching research and practical explorations integrating AI with health assessment training, thereby promoting professional development. For instance, teachers can optimize teaching strategies by learning machine learning algorithms, analyze student learning behaviors using natural language processing (NLP) technology, or create immersive learning environments through virtual reality (VR) systems. Furthermore, schools could invite AI experts to deliver lectures sharing cutting-edge research findings and real-world application cases, helping teachers better understand and apply AI technologies. These measures not only improve teaching capabilities but also stimulate students' learning interest, ultimately enhancing both teaching quality and efficiency.

5.2 Improve the Construction of Teaching Resources

To further enhance the quality and effectiveness of health assessment practical training, we will increase investment in AI teaching resources and establish a comprehensive intelligent resource repository. This repository should include virtual case libraries, simulated training scenarios, AI-guided courses, and learning analytics data. Through these resources, students can gain more vivid and intuitive learning experiences, thereby deepening their understanding and mastery of health assessment knowledge. Additionally, we encourage collaboration between educators and technical professionals to jointly develop and innovate high-quality AI teaching materials, ensuring continuous updates to meet evolving educational needs. Simultaneously, we actively seek partnerships with medical institutions and tech companies to integrate authentic clinical data and advanced AI technologies, continuously enriching and refining our resource repository.

5.3 Optimize the Teaching Evaluation System

In optimizing the teaching evaluation system, we recognize that traditional assessment methods can no longer fully meet the demands of health assessment practical training in AI environments.But AI can use computer vision, sensor data and other technologies to capture and quantify the practical operations of nursing students (such as injection, sterile technology, first aid processes), replacing the traditional evaluation model that relies on teachers' subjective observations to improve the objectivity and consistency of evaluation [9]. Therefore, we are committed to establishing a diversified evaluation framework that comprehensively assesses students 'theoretical knowledge mastery, practical skills, innovative thinking, and performance in AI learning environments. By leveraging AI technologies, we enable full-process tracking and evaluation of student learning. For instance, intelligent scoring systems objectively evaluate practical operations, while learning analytics systems assess students' progress. Additionally, we emphasize self-evaluation and peer review, encouraging students to engage in self-reflection and mutual learning to enhance collective improvement. To further enhance the comprehensiveness and accuracy of the evaluation system, we have introduced various tools including online tests, project reports, case analyses, and simulation experiments. These methods not only fully reflect students' learning outcomes but also effectively promote their holistic development. Simultaneously, we have established a feedback mechanism to promptly provide assessment results and personalized improvement suggestions, helping students identify strengths and weaknesses to formulate more scientific learning plans [10]. Through these measures, we aim to build a more scientific, comprehensive, and dynamic teaching evaluation system that delivers superior learning experiences and growth opportunities for students.

6 CONCLUSIONS

Artificial intelligence (AI) technology has introduced innovative approaches to health assessment training education, demonstrating significant advantages in addressing current teaching challenges and enhancing instructional quality. It holds tremendous potential for improving educational standards and cultivating high-quality technical professionals [7]. By applying AI to health assessment training, we can enrich teaching resources, expand practical scenarios, and implement personalized instruction, thereby effectively boosting students 'learning outcomes and practical skills. Moreover, AI can provide customized learning plans and feedback based on students' progress and comprehension levels, helping them better master health assessment knowledge and competencies [11]. However, achieving deep integration of AI with health assessment training requires sustained efforts in faculty development, teaching resource construction, and evaluation system optimization. Looking ahead, as AI continues to evolve, its application prospects in health assessment training will become even more extensive [12]. Future intelligent teaching systems may integrate big data analytics and machine learning algorithms to monitor students' learning status and progress in real-time, offering personalized guidance and recommendations [13]. Additionally, combining AI with emerging technologies like virtual reality and augmented reality could create more immersive and interactive learning experiences. We have every reason to believe that AI will drive greater breakthroughs in cultivating health assessment professionals and propel the entire industry toward smarter, more efficient development.

COMPETING INTERESTS

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ARTIFICIAL INTELLIGENCE IN DIGITAL PATHOLOGY: REAL-WORLD PERFORMANCE EVALUATION IN A CANCER DIAGNOSIS COHORT FROM CHINA

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Abstract: This paper focuses on the core technological breakthroughs in the integration of digital pathology slide systems and artificial intelligence (AI), with precision cancer diagnosis as the entry point. It deeply analyzes the innovative applications of multi-scale feature fusion algorithms, self-supervised learning models, and multi-omics integration technologies in clinical practice. Through specific cases such as breast cancer HER2 quantification and lung cancer subtype classification, it elaborates how AI-assisted diagnosis improves the consistency of biomarker detection (HER2 assessment consistency increased from 93% to 99%), enhances diagnostic efficiency (doubling the number of cases processed), and optimizes survival prediction accuracy (C-index increased by an average of 1.1-5.5%). It also analyzes the standardization dilemmas and model generalization challenges in technology implementation, and looks forward to the construction path of a human-machine collaborative diagnosis ecosystem, providing references for the clinical transformation of digital pathology.
Keywords: Digital pathology slides; Artificial intelligence; Cancer diagnosis; Multi-omics integration; Clinical transformation

1 INTRODUCTION: AI RECONSTRUCTING THE PARADIGM OF PATHOLOGICAL DIAGNOSIS

Pathological diagnosis, as the "gold standard" for cancer diagnosis and treatment, its traditional model is facing dual challenges: on the one hand, manual slide reading has inherent subjectivity, such as the inter-observer consistency of breast cancer HER2 assessment is only 93%, and the consistency of Ki67 quantification is even lower at 77%[1]; on the other hand, the demand for precision medicine promotes the transformation of pathological diagnosis from morphological description to molecular feature interpretation, and traditional microscopes can no longer meet the needs of "morphology-molecule" correlation analysis. The digital pathology slide system realizes the digital transformation of pathological images through whole slide imaging (WSI) technology.the application of AI in the analysis of OCT images extends to complex conditions such as Stargardt disease, where traditional segmentation methods struggle due to degeneration. The in-depth involvement of AI algorithms breaks through the limitations of human vision, forming a new closed loop of "scanning-analysis-diagnosis"[2]. This breakthrough lays a solid foundation for the in-depth application of AI and machine learning tools in pathology, making it possible to mine sub-visual morphological features in stained tissue specimens - these features are often unique manifestations of complex biological processes, and their analysis through AI technology can provide key basis for precise patient management and treatment plan optimization[3].
Cancer has significant diversity in signal transduction and transcriptional networks, which makes the development of biomarkers based on a single gene or protein face great challenges. However, the combination of digital pathology and AI provides new ideas to solve this problem[3]. The application of AI in digital pathology mainly focuses on deep neural networks and manual feature extraction methods, which not only improves the efficiency of pathological image analysis, but also opens up new paths for the development of biomarkers, enabling more accurate identification and classification of different types of cancers, and providing strong support for personalized treatment[3]. However, the development of this field still faces many obstacles, such as the need for well-planned validation datasets, improved regulatory approval mechanisms, and reasonable reimbursement strategies, which are all key issues to promote the transformation of AI technology from the laboratory to the clinic[3].
In recent years, with the emergence of innovative models such as Inter-MIL and BEPH, the application of AI in the field of digital pathology has evolved from an auxiliary tool to a technical system with independent diagnostic capabilities[4,5]. These models can not only accurately identify tumor microenvironment features, but also predict molecular subtypes and patient prognosis through multi-omics integration, making the digital pathology slide system a key link connecting morphological phenotypes and molecular mechanisms. This paper will reveal the core value of digital pathology in precision cancer diagnosis around three dimensions: AI-driven technological breakthroughs, clinical verification cases, and standardization construction.

2 CORE TECHNOLOGICAL BREAKTHROUGHS: FROM FEATURE EXTRACTION TO MULTI-MODAL INTEGRATION

2.1 Multi-Scale Feature Learning: Innovation in Subtype Classification by Inter-MIL

Accurate identification of cancer molecular subtypes is a prerequisite for personalized treatment, but traditional methods rely on gene sequencing, which is costly and time-consuming. The Inter-MIL framework achieves a breakthrough in directly predicting cancer molecular subtypes from WSI through the iterative optimization mechanism of multi-instance learning (MIL)[4]. This model innovatively constructs a slide-level feature pool, reduces noise interference through adversarial optimization, and makes attention weights automatically focus on key structures such as tumor regions and cell nuclei.

In the validation of the TCGA dataset, Inter-MIL performed better than traditional MIL methods in multiple subtype classification tasks such as ovarian cancer and colorectal cancer, especially in small sample scenarios. Its core innovation lies in simulating the diagnostic logic of pathologists: first observing the global structure through low-power microscopy, then analyzing detailed features with high-power microscopy, realizing the organic integration of multi-scale features. This mechanism enables the model to achieve accuracy comparable to immunohistochemical detection in predicting gastric cancer HER2 status by quantitatively calculating the proportion of high-expression regions.

2.2 Revolution in Self-Supervised Learning: Breakthrough in Generalization Ability of BEPH Model

The high cost of data annotation has always been a bottleneck in the development of pathological AI, but the BEPH model breaks this limitation through self-supervised learning strategies. The model is pre-trained on 11 million unlabeled pathological images, using masked image modeling (MIM) technology to enable AI to learn pathological features like a "jigsaw puzzle", requiring only 25% of labeled data to achieve the performance of traditional models with full data[5]. In lung cancer subtype classification tasks, the accuracy of BEPH is as high as 99.99%, and the AUC of renal cancer subtype classification reaches 0.994, close to the level of pathological experts.

The cross-cancer adaptation ability of BEPH is particularly prominent, with its pre-training covering 32 types of cancers. In breast cancer survival prediction, only WSI images can achieve a C-index 5.5% higher than traditional models[5]. The model's robustness to image quality is also significant, maintaining high accuracy even when the resolution is reduced by 70%, which provides possibilities for equipment adaptation in primary hospitals. This "pre-training-fine-tuning" paradigm is analogous to "learning a common language first, then practicing dialects", laying the foundation for the large-scale application of pathological AI.

2.3 Multi-Omics Integration: Morphology-Molecule Association by OmiCLIP

The ultimate goal of digital pathology is to "see images and recognize genes". The OmiCLIP model takes a key step through visual-transcriptome contrastive learning. The model constructs an ST-bank dataset containing 32 organs and 2.2 million pairs of images and transcriptome data, encoding highly expressed genes into "text sentences", enabling H&E images and gene expression to achieve precise alignment in the embedding space[6].

In clinical applications, the five modules of the supporting platform Loki show strong functions: Loki Align realizes cross-sample tissue alignment with higher precision than traditional methods; Loki Decompose can infer cell type composition from pathological images, and its performance surpasses tools such as Tangram in triple-negative breast cancer analysis. This technological breakthrough enables the pathology department to predict key molecular features such as tumor mutation burden and immune checkpoint expression without additional sequencing, providing immediate support for precise treatment decisions(Table 1).

Table 1 Comparison of Core Performance of Mainstream AI Models in Digital Pathology

Model Name	Core Technology	Covered Cancer Types	Classification Accuracy	AUC Value	Increase in Survival Prediction C-Index
Inter-MIL	Multi-scale feature fusion	12 types	89.6-94.3%	0.92-0.96	1.1-3.2%
BEPH	Self-supervised learning	32 types	92.5-99.99%	0.95-0.994	2.3-5.5%
OmiCLIP	Multi-omics integration	18 types	88.2-93.7%	0.91-0.95	1.8-4.1%

3 CLINICAL TRANSFORMATION VERIFICATION: FROM LABORATORY TO PATHOLOGY DEPARTMENT

3.1 Improvement in Accuracy of Biomarker Quantification

Breast cancer biomarker assessment is a benchmark field for clinical application of AI. A multi-center study published at the 2024 USCAP Annual Meeting showed that the AI-assisted system using the Mindpeak algorithm increased the inter-observer consistency of HER2 assessment from 93% to 99%, and the consistency of Ki67 quantification even jumped from 77% to 95% [1,7]. In 11 critical cases (near the 5% proliferation threshold), AI avoided subjective bias in manual interpretation through precise counting.As shown in Figure 1, the integration of AI into the diagnostic workflow led to a marked improvement in inter-observer agreement among pathologists.

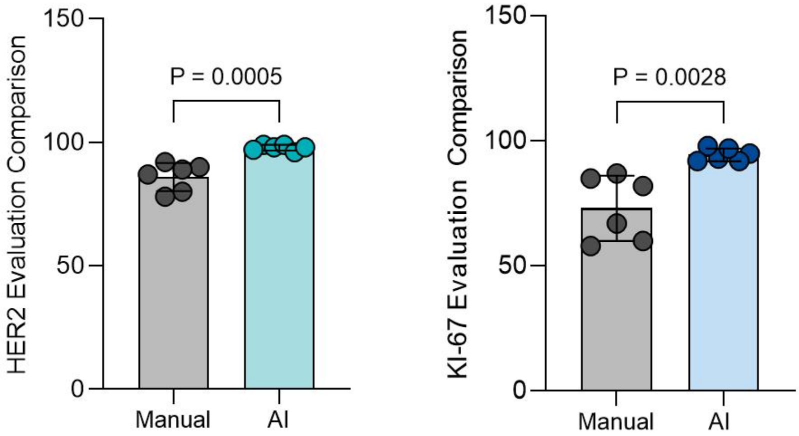

Figure 1 Comparison of HER2 and Ki67 Assessment Consistency between Manual and AI-Assisted Methods (Data source: Multicenter study and practice at the Affiliated Hospital of Hubei University of Medicine)

Practice at Renmin Hospital further confirmed that AI assistance doubled the number of cases processed by pathologists per week, while reducing the rate of diagnostic modifications in pre-MDT reviews significantly[8]. This "dual value of quality and efficiency improvement" stems from two advantages of AI: first, the fatigue-free stable judgment ability; second, the accuracy of quantitative analysis, such as the calculation error of the proportion of HER2-positive regions can be controlled within 1%.

3.2 Survival Prediction and Treatment Response Assessment

The self-supervised learning BEPH model demonstrates excellent performance in predicting tumor mutational burden (TMB) and VHL mutation status. By analyzing whole-slide images and somatic mutation data from 350 clear cell renal cell carcinoma (CCRCC) patients, the SSL-ABMIL model achieved high AUROC values of 0.83 and 0.8 for predicting TMB and VHL mutations, respectively. This demonstrates that self-supervised learning can effectively extract information from histological features, thereby establishing a link between tumor morphology and molecular biology [9]. This ability stems from AI's capture of spatial heterogeneity of the tumor microenvironment, such as immune cell infiltration patterns, stromal fibrosis degree and other features closely related to prognosis.

In the prediction of immunotherapy response, AI can early identify responders and non-responders by analyzing changes in WSI before and after treatment. Studies have shown that regions with increased CD8+T cell infiltration after treatment show significant attention enrichment in AI heatmaps, and this dynamic monitoring ability provides a pathological basis for adjusting treatment plans[10].We further evaluated the prognostic value of the BEPH deep learning model using whole-slide images (WSIs) across four major cancer types: As illustrated in Figure 2, the AI model consistently achieved higher concordance indices (C-index) compared to conventional clinical models based on histopathological and clinical variables alone.

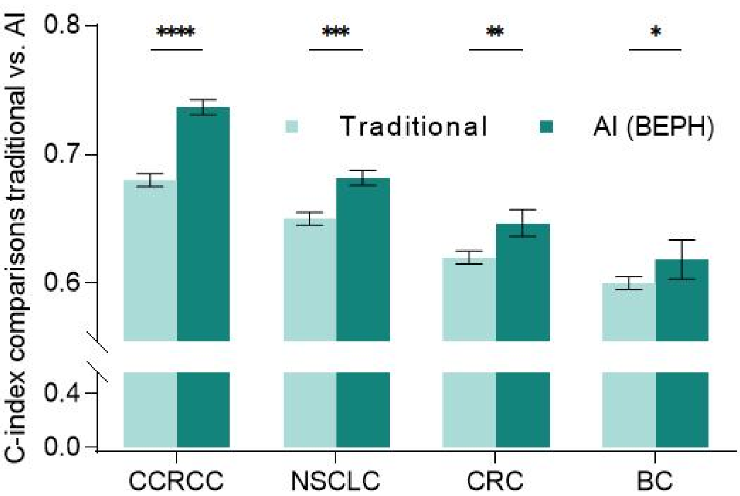

Figure 2 Comparison of C-Index in Survival Prediction between Traditional Pathological Methods and AI Models in

Different Cancer Types; Clear Cell Renal Cell Carcinoma (CCRCC), Non-Small Cell Lung Cancer (NSCLC), Colorectal Cancer (CRC), and Breast Cancer (BC)

3.3 Breakthrough in Technical Accessibility in Primary Medical Care

The decentralized application of digital pathology faces two major obstacles: equipment cost and image quality. The low-resolution robustness of the BEPH model (maintaining high accuracy at 224×224 pixels) reduces the reliance on high-end scanners; while the secondary compression technology developed by Hospital reduces image storage requirements by 60% without losing diagnostic information, significantly reducing data transmission costs[5,8].

In the pilot project of hospitals in remote areas, the AI-based digital pathology system increased the compliance rate of HER2 detection from 78% to 92%, avoiding a large number of misdiagnoses and mistreatments. This technology sinking not only improves the diagnostic level of primary medical institutions, but also realizes the balanced allocation of high-quality pathological resources through remote consultation platforms(Table 2).

Table 2 Application Effects of AI-Assisted Digital Pathology in Primary Hospitals

Indicator	Before Application	After Application	Improvement
HER2 detection compliance rate	78%	92%	+14%
Diagnostic report issuance time	48 hours	12 hours	-75%
Remote consultation coverage	32%	89%	+57%
Misdiagnosis rate	9.3%	3.1%	-6.2%

4 CHALLENGES AND COUNTERMEASURES: STANDARDIZATION AND GENERALIZATION DILEMMAS

4.1 Fragmentation Dilemma of Data Formats

Digital pathology systems from different manufacturers adopt proprietary formats, such as Aperio's.svs and Leica's.scn formats, which are incompatible, making it difficult for AI models to be applied across platforms. Although the DICOM standard has been introduced into the field of pathology, in actual promotion, there are still problems such as inconsistent scanning parameters and differences in staining agents, forming a "digital Babel"[11,12].

The solution of ruijin Hospital is worthy of reference: realizing seamless connection of different devices through standardized data collection processes and format conversion interfaces; adopting adaptive image enhancement algorithms to eliminate interference caused by uneven staining[8]. This "soft compatibility" strategy is more feasible than mandatory hardware standards, and has enabled the hospital's digital pathology data interoperability rate to reach 98%.

4.2 "Achilles' Heel" of Model Generalization

Pathological images in the real world have huge variations, such as low-contrast slides can cause the SAM model to misjudge inflammatory regions as tumors. Although BEPH performs excellently in breast cancer subtype classification, it still has the risk of misdiagnosis in the face of rare subtypes such as micropapillary carcinoma. This limitation stems from insufficient coverage of training data and the complexity of clinical scenarios[5].

Multi-center joint training is an effective countermeasure: the PHARAOH crowdsourcing platform integrates multi-institutional data through weakly supervised learning, significantly improving the robustness of the model in melanoma diagnosis; while the "federated learning" model realizes knowledge sharing under the premise of protecting data privacy, enabling the model to obtain sufficient training signals even in small sample cancer types[13].

4.3 Balance between Regulation and Ethics

The regulatory framework for AI pathological diagnosis is still to be improved. The first AI-assisted pathology system approved by the FDA in 2024 is limited to specific cancer types and requires final review by pathologists[14]. This "human-led" model how to balance with the high accuracy of AI has become the focus of ethical controversy. In addition, the lack of interpretability of attention heatmaps may lead to "black box decisions", affecting clinical trust.

The exploration of the Path-X framework provides new ideas: identifying key diagnostic features through SHAP value analysis and mapping them back to the original pathological sections, making the AI decision-making process visible[15]. This "transparent AI" not only meets regulatory requirements, but also helps pathologists understand the judgment logic of AI, achieving human-machine collaborative efficiency.

5 OUTLOOK: BUILDING A HUMAN-MACHINE COLLABORATIVE DIGITAL PATHOLOGY ECOSYSTEM

The future development of digital pathology slide systems will show three major trends: at the technical level, generative AI will break through data bottlenecks, expand training sets by synthesizing virtual pathological sections, which is especially beneficial for rare disease research[16]; Major tech companies like Google have also conducted extensive exploration into integrating edge computing with AI to address the challenges of rare disease diagnosis. By deploying optimized AI models on edge devices, these platforms enable efficient data processing and analysis in resource-constrained environments. This approach not only enhances diagnostic efficiency but also provides the technical foundation for broader adoption of edge computing in healthcare applications[17].

The role of pathologists will shift from image interpretation to comprehensive decision-making, while AI will undertake repetitive work such as primary screening and quantification. This division of labor has been effective in breast cancer diagnosis and treatment: AI is responsible for precise counting of HER2/Ki67, and doctors focus on comprehensive judgment of complex cases, enabling simultaneous improvement of diagnostic efficiency and accuracy[1,7]. With the deepening of multi-omics integration, the digital pathology slide system will become an integrated platform for cancer early screening, efficacy monitoring and prognosis evaluation, promoting precision medicine into a new era of "morphology-molecule" integration. Despite the current challenges, with the continuous advancement of technology and the continuous improvement of datasets, the role of AI in precision oncology will become increasingly prominent, bringing better prognosis and quality of life to patients[3].

6 CONCLUSION

AI-driven digital pathology slide systems have shown transformative value in precision cancer diagnosis, with core breakthroughs in realizing the paradigm shift from qualitative description to quantitative analysis, and from isolated diagnosis to multi-omics integration. Clinical data fully prove that AI assistance can significantly improve the consistency of biomarker assessment, enhance diagnostic efficiency and optimize survival prediction[1,5,9]. Despite facing challenges such as standardization and generalization, through technological innovation and model optimization, digital pathology is gradually building a new human-machine collaborative diagnosis ecosystem.

The key to future development lies in balancing technological advancement and clinical practicality, ensuring interpretability and safety while improving model performance. With the improvement of regulatory frameworks and the accumulation of multi-center data, digital pathology slide systems are expected to become the core infrastructure for precision cancer diagnosis and treatment, providing strong support for achieving the goal of "every patient receives the best diagnosis".

COMPETING INTERESTS

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PRACTICE AND EXPLORATION OF CURRICULUM IDEOLOGY AND POLITICS IN DIAGNOSTICS OF TRADITIONAL CHINESE MEDICINE UNDER OBE ORIENTATION

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Abstract: This paper explores the teaching model of Curriculum Ideology and Politics in *Diagnostics of Traditional Chinese Medicine* based on the OBE concept, aiming to achieve the trinity teaching goal of "knowledge impartment, ability cultivation, and value guidance". By reverse-designing teaching objectives, integrating professional knowledge such as the Four Diagnostic Methods and syndrome differentiation with ideological and political elements like medical ethics and cultural inheritance, adopting methods such as blended teaching, scenario simulation, and case-based teaching, and constructing a "three-dimensional evaluation" (knowledge/skills/literacy), the practice was carried out in the majors of Integrated Traditional Chinese and Western Medicine Clinical Medicine and Acupuncture-Moxibustion & Tuina. This effectively improved students' syndrome differentiation thinking ability, medical ethics cognition level, and clinical skills.
Keywords: OBE; Diagnostics of traditional Chinese medicine; Curriculum ideology and politics; Teaching practice

1 INTRODUCTION

Outcome-Based Education (OBE) is an education model for students that assist the teachers to outline the cause and evaluation with goals in mind to achieve results such as Program Outcome (PO) and Course Outcome (CO) which forms the basis for evaluating student performance [1]. OBE has brought along a significant development in health professions education in the past decade,it is valuable for ensuring graduate quality and facilitating global movement of healthcare workers [2]. OBE as an educational philosophy oriented towards learning outcomes, is reshaping the value logic of higher education through reverse-designing teaching processes and focusing on closed-loop ability cultivation. Curriculum Ideology and Politics, which undertakes the fundamental mission of fostering virtue through education, requires integrating value guidance throughout the entire educational process [3]. The organic integration of the two not only responds to the urgent need for "excellence in both medical skills and ethics" in medical talent cultivation in the new era but also provides methodological support for the in-depth coupling of professional courses and ideological and political education. Through the outcome-oriented framework of OBE, ideological and political elements are transformed into observable and evaluable learning outcomes, realizing the trinity of knowledge impartment, ability cultivation, and value shaping.

As a bridge course connecting the basic theories of Traditional Chinese Medicine (TCM) and clinical practice, *Diagnostics of Traditional Chinese Medicine* requires both a solid theoretical foundation and the refinement of clinical thinking ability for its core thinking of "syndrome differentiation and treatment". The course itself contains rich traditional cultural genes and medical ethics connotations, from the preventive thought of "treating diseases before they occur" in *Huangdi Neijing* (Yellow Emperor's Inner Canon) to the diagnostic wisdom of "observing the pulse and symptoms, knowing the inversion, and treating according to the syndrome" in *Shanghan Lun* (Treatise on Febrile Diseases), from Bian Que's diagnostic skills to Sun Simiao's "Great Medical Sincerity". These contents provide a natural fertile ground for Curriculum Ideology and Politics. Introducing the OBE concept into the teaching reform of this course can shape students' professional values imperceptibly while mastering the Four Diagnostic Skills and syndrome differentiation methods by clarifying the ideological and political education outcome goals, designing immersive teaching experiences, and constructing a diversified evaluation system.

Current medical education is facing the challenge of transforming from "knowledge-oriented" to "ability-oriented". Traditional teaching of *Diagnostics of Traditional Chinese Medicine* has problems such as disconnection between theory and practice and formalization of ideological and political education, which urgently need to be broken through by innovating teaching models. Based on the OBE teaching concept, this study systematically constructs the Curriculum Ideology and Politics teaching system of *Diagnostics of Traditional Chinese Medicine*, explores the collaborative path of "professional knowledge impartment-clinical ability cultivation-medical ethics literacy cultivation", and provides a replicable and promotable practical paradigm for the construction of ideological and political courses in TCM. This exploration not only helps to improve the teaching quality of TCM diagnostics but also has important practical significance for cultivating new-era TCM talents with cultural confidence, professional ethics, and innovative ability.

2 CONSTRUCTION OF OBE-ORIENTED CURRICULUM IDEOLOGY AND POLITICS TEACHING SYSTEM

2.1 Teaching Objective Design

The design of teaching objectives under the guidance of the OBE concept follows the principle of reverse mapping, that is, deducing the specific teaching requirements of the *Diagnostics of Traditional Chinese Medicine* course from the ultimate outcomes of TCM talent cultivation. A "knowledge-ability-value" three-dimensional objective system[4] is constructed to transform abstract ideological and political education requirements into operable and observable learning outcomes. The knowledge dimension focuses on professional core contents such as the Four Diagnostic Skills and syndrome differentiation methods; the ability dimension emphasizes practical abilities such as clinical thinking and doctor-patient communication; the value dimension highlights ideological and political connotations such as medical ethics literacy and cultural confidence, forming an interlocking objective chain.

This objective design breaks the limitation of traditional teaching that emphasizes theory over practice. By clarifying specific standards for what students can do after learning, Curriculum Ideology and Politics is transformed from implicit requirements to explicit goals. For example, in pulse diagnosis teaching, students are not only required to "master the characteristics of 28 pulses" (knowledge objective) but also emphasized to "be able to explain pulse changes in combination with the patient's psychological state" (ability objective), and finally achieve the value objective of "understanding the bio-psycho-social medical model", realizing the in-depth coupling of professional education and ideological and political education.

2.2 Teaching Content Optimization

The shift toward OBE is not merely a curricular adjustment but a transformative opportunity to redefine how clinical readiness is cultivated [5]. The curriculum content reconstruction adopts a "double-helix integration" model, weaving TCM diagnostic professional knowledge and ideological and political elements into a mutually supportive content system. By systematically sorting out the course chapters, while maintaining the knowledge main line of "Four Diagnostics-Syndrome Differentiation-Diagnostic Synthesis", three ideological and political auxiliary lines of "medical ethics cultivation-cultural inheritance-thinking methods" are embedded, forming a content pattern of "one chapter, one theme; one diagnosis, one ideological and political element".

Content optimization pays special attention to the natural integration of ideological and political elements. In the teaching of "tongue inspection", by displaying photos of tongue coatings of different constitutions, students are guided to understand the individualized diagnosis and treatment thought of "treating according to individual differences". In the inquiry chapter, the historical allusion of "Zhang Zhongjing and Wang Can" is used to explain the preventive medical thought of "excellent doctors treat diseases before they occur", avoiding ideological and political content becoming an additional "label". The TCM diagnostic principles such as "inferring the internal from the external" and "observing the subtle to know the obvious" are connected with the epistemology of materialist dialectics to help students establish scientific thinking methods.

2.3 Teaching Method Innovation

In the teaching implementation level, a "three-dimensional interactive" teaching model is constructed. Blended teaching is used to break the boundaries of time and space, scenario simulation teaching is used to strengthen clinical experience, and case-based teaching is used to deepen thinking training, forming a diversified and three-dimensional teaching method system. Blended teaching adopts a three-stage design of "pre-class, in-class, and post-class"[6]: pre-class, classic medical cases and ideological and political case preview materials are pushed; in-class, flipped classroom mode is adopted to organize students to discuss; post-class, assignments are arranged, requiring students to present the diagnostic reasoning process with mind maps. Scenario simulation teaching focuses on building a standardized patient (SP) resource library, training simulated patients covering different ages, genders, and disease types, and designing case scripts from simple to complex. Case-based teaching uses the professional dimension to analyze diagnostic basis and differential points, the ideological and political dimension to explore the value orientation behind doctors' decisions, and the innovation dimension to discuss the optimization space of diagnosis and treatment plans.

3 EXPLORATION OF PRACTICAL PATHS FOR CURRICULUM IDEOLOGY AND POLITICS TEACHING

3.1 Integration of Ideology and Politics in Theoretical Teaching

Theoretical teaching adopts a three-stage infiltration model of "knowledge points-case chain-values", naturally integrating ideological and political education into the process of professional knowledge teaching. In the teaching of the "complexion inspection" chapter, starting with the theoretical entry point of "the essence and five colors are the glory of qi" from *Neijing*, by analyzing the diagnostic significance of "pale complexion indicating deficiency syndrome", the discussion is extended to the TCM view of life of "unity of body and spirit". Ancient medical cases are introduced to show how they judged the patient's emotional state through complexion inspection and adjusted the diagnosis and treatment plan, enabling students to understand the profound connotation of "doctors not only treat diseases but also treat people".

In the inquiry teaching link, a situational teaching of the "Ten-Question Song" is designed to transform traditional inquiry content into modern doctor-patient communication scenarios. Taking "inquiring about cold and heat" as an example, combined with the classic statement in *Shanghan Lun* that "a patient with high fever but wants to wear clothes has heat on the skin but cold in the bones", students' meticulous observation ability is cultivated; through simulated inquiry scenarios, students are trained to use humanistic care questions such as "What makes you feel most uncomfortable now" to avoid mechanically applying inquiry items.

In theoretical teaching, special attention is paid to excavating ideological and political elements in TCM classics. When teaching "pulse diagnosis", the original text of *Mai Jing* (Pulse Classic) is quoted to explain the theoretical basis of cun-kou pulse diagnosis, and through the story of Wang Shuhe compiling *Mai Jing* over ten years, students are cultivated with the academic perseverance spirit of "sitting on the bench for ten ye

ars without distraction". At the end of each chapter, a "medical ethics micro-discussion" session is set up, such as discussing "how to inform patients of bad news" after inspection, and reflecting on whether technological progress will weaken doctors' benevolence after pulse diagnosis, so that value guidance runs through the entire process of theoretical learning.

3.2 Strengthening of Practical Teaching Links

Practical teaching constructs a three-stage training system of "basic training-comprehensive simulation-clinical application", integrating ideological and political literacy cultivation into all links of diagnostic skill training. The training center is equipped with TCM pulse diagnosis instruments, inspection instruments, and TCM clinical diagnosis and treatment thinking training systems for students to conduct standardized training. The pulse diagnosis instrument is simulated, and students compare and analyze the differences between their own finger sensations and different pulses to cultivate a rigorous and realistic scientific attitude; tongue diagnosis training uses real tongue coating images in the system database to train students' differential diagnosis ability of "same disease, different tongue coatings; different diseases, same tongue coating", helping them understand the flexibility and principle of TCM syndrome differentiation and treatment.

Diagnostic thinking training adopts a closed-loop design of "case deduction-scenario simulation-reflection and improvement". In the basic stage, logical training of syndrome differentiation thinking is carried out, and students need to sort out the four diagnostic data according to the logical chain of "symptoms-disease location-disease nature-syndrome name" and draw visual thinking maps to cultivate systematic analysis ability; in the advanced stage, SP scenario simulation is implemented, and students are grouped to play doctors and patients to complete the whole process training from consultation to diagnosis. SP case design specially adds ethical dilemma elements to cultivate students' professional ethical decision-making ability.

4 CONCLUSION

For medical schools providing outcome-based education, systematic mission statement and continuous improvement are prerequisites [7]. We will further develop a smart curriculum ecosystem and actively promote AI-assisted teaching innovations. By training intelligent tutoring systems using big data from traditional Chinese medicine diagnosis, we can automatically identify force deviation errors in students' pulse diagnosis operations and provide corrective prompts,investigate innovative applications of Convolutional Neural Networks to develop models proficient at recognizing facial expressions [8]. Through natural language processing technology, we analyze logical flaws in students' medical record documentation to generate personalized improvement plans. We will deepen the organic integration of ideological and political elements by establishing a dynamic update mechanism for these components and incorporating contemporary teaching cases that reflect modern characteristics. Expanding clinical practice dimensions, we will conduct community health volunteer services to enhance TCM diagnostic skills while cultivating noble professional ethos and fine traditional virtues.

COMPETING INTERESTS

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EXPERIENCE AND INSPIRATION FROM INTERNATIONAL SCIENCE EDUCATION DEVELOPMENT: A COMPARATIVE STUDY BASED ON POLICIES, RESOURCES AND PRACTICES

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Abstract: Against the backdrop of intensifying global scientific and technological competition and social change, science education has become a core indicator for measuring a country's innovation capabilities and future competitiveness. This article systematically examines and analyzes the reform experiences and development trends of leading science education countries and regions in terms of top-level policy design, resource supply ecosystems, and educational practice approaches through an international comparative perspective. The research reveals that international science education exhibits characteristics such as strategic policy, curriculum literacy, digital resources, teacher professionalization, and collaboration within and beyond schools. These countries promote interdisciplinary integration through top-level design, build open resource ecosystems based on digital platforms, strengthen professional support systems for teachers, and actively promote educational collaboration among diverse stakeholders such as schools, families, and communities. This study concludes that these international experiences offer important insights for my country in building a high-quality science education system. This research aims to provide international references and localized approaches for optimizing and innovating my country's science education system.
Keywords: Science education; International comparison; Education policy; Digital resources

1 INTRODUCTION

Driven by globalization and the Fourth Industrial Revolution, technological innovation represented by artificial intelligence and big data is profoundly reshaping social structure and future lifestyles. As a key way to cultivate innovative talents and improve the scientific literacy of the people, science education has become an important strategic area for education reform in various countries. The results of the PISA 2022 test released by the Organization for Economic Cooperation and Development (OECD) show that students' scientific literacy is not only closely related to their future academic careers, but also has a profound impact on the country's innovation capabilities and long-term competitiveness [1]. Therefore, building a science education system that adapts to the needs of future development has become a common goal and key task of education reform in various countries. However, in the process of promoting the development of science education, different countries face different social environments. How to find a balance between global trends and local realities and build a science education system that is in line with the development of the times and in line with the national conditions is still a common challenge. International experience shows that the reform of science education usually covers three core levels: policy guidance, resource supply and educational practice. The policy level focuses on top-level design and curriculum standard innovation, the resource level emphasizes digitalization, openness and multi-subject collaboration, and the practice level focuses on the deep integration of formal and informal learning fields.

How to build a science education system that adapts to the changing times and aligns with national conditions is a common challenge faced by all countries. Based on this, this article aims to systematically review the relevant policy documents of countries and regions with advanced science education development, as well as those of international organizations, analyzing their reform experiences and implementation paths in terms of policies, resources, and practices. Through comparative analysis, this article aims to reveal the common trends and differences in international science education reform, hoping to provide reference and inspiration for the deepening reform and innovative development of science education in my country.

2 POLICY TRENDS IN THE DEVELOPMENT OF INTERNATIONAL SCIENCE EDUCATION

2.1 Strategic Policy Layout: Systematically Building a New Framework for Science Education

International organizations and governments have placed science education in a national strategic position and attached importance to the top-level design of science education. Since 2024, UNESCO has promoted the "Revitalizing STEM Education" project, advocating the integration of STEM education with the Sustainable Development Goals SDG4 (quality education) and SDG9 (industrial innovation) to address the digital divide and gender gap. Secondly, many countries have released STEM education strategic plans. For example, the United States has released the "Federal STEM Education Strategic Plan (2024–2028)" and the "Computational Literacy Guidelines" [2], promoting national STEM education through systematic design [3]. Ireland, a member state of the European Union, has issued the "STEM

Education Implementation Plan (2023–2026)", proposing a full coverage training program from preschool to secondary school. The Finnish Ministry of Education and Culture released its national STEM strategy in 2023, which clearly stated the goal of achieving universal information literacy and lifelong learning by 2030 [4]. Overall, international science education policies are characterized by being guided by students' core literacy, focusing on interdisciplinary integration, and supported by digital technology, fully reflecting the consensus on cultivating future scientifically literate talents.

2.2 Curriculum And Teaching Reform: Emphasizing Core Literacy and Inquiry Practice

Curriculum standards are the bridge between macro-policies and micro-teaching. Countries have updated their science curriculum standards to meet the needs of interdisciplinary integration and core literacy cultivation. When updating their national curriculum, many countries emphasize inquiry and interdisciplinary teaching as core teaching activities. For example, the United States' Next Generation Science Standards (NGSS) proposed a "three-dimensional learning framework", including "science and engineering practices", "interdisciplinary core concepts" and "disciplinary core ideas", emphasizing that students explore knowledge with a scientist's mindset in real problem situations and realize knowledge construction [5]. The United Kingdom's National Curriculum for Science and the Australian Curriculum: Science (9.0) also emphasize inquiry-based and interdisciplinary teaching, encouraging students to improve their scientific literacy and critical thinking through experiments, projects and competitions [6].

Curriculum reforms are accompanied by changes in teaching methods. Countries are promoting teaching models such as inquiry-based learning, collaborative learning, and flipped classrooms to enhance students' critical thinking and practical skills. For example, some high schools in Japan are using collaborative inquiry and practice, while German schools are introducing research-based experiments and real-data analysis to strengthen students' scientific inquiry skills. Meanwhile, internationally, there is a growing emphasis on cultivating students' scientific literacy and global competence. Many countries are incorporating global issues such as climate change and sustainable development into science curricula to enhance students' understanding of the interaction between science and society. For example, Finland's core curriculum framework, centered on "phenomenon-based learning," encourages students to engage in interdisciplinary inquiry around global issues such as climate change and energy, fostering critical thinking and independent problem-solving skills. Countries like the United Kingdom and Australia emphasize the application and practice of scientific literacy. For example, Australia is implementing the "Science Innovation Competition," and German schools are establishing "Natural Science Laboratories" to provide students with rich experimental experiences. The core goal of science education has shifted from simply imparting knowledge to cultivating students' ability to address complex problems. This shift from a knowledge-based to a competency-based approach highlights the importance of advancing curriculum and teaching reform simultaneously.

2.3 Teacher Professional Development: Building a Systematic Support System

Teacher professional development is generally regarded as the key to whether the reform can be implemented. International experience shows that countries have established a multi-level and systematic teacher professional development system to ensure that teachers are able to meet the new teaching requirements. The US "Standards for Science Teacher Training" and Australia's "Strong Beginnings" report both emphasize that science teachers should have the ability to teach and instruct across disciplines [7-8]. In addition, the OECD (2020) survey shows that most countries require teachers to regularly participate in school-based training [9], online courses and cross-school exchanges. The EU's "Europe 2020 Strategy" and "European Digital Agenda" support member states in carrying out teacher STEM capacity building projects. The UK has established a national STEM learning center to provide summer camp training for science teachers, the US NSF provides a variety of teacher development programs, and the Singapore Ministry of Education organizes science education webinars and workshops through the "Teacher Development Committee" to help teachers master digital teaching and project-based learning methods. Countries such as the Netherlands have established communication and cooperation platforms such as "teacher communities" to encourage teachers to share experiences and grow together, and have incorporated participation in professional development into career advancement and salary incentive systems, effectively enhancing teachers' motivation for development [10].

3 THE SUPPLY MODEL AND ECOLOGY OF SCIENTIFIC EDUCATION RESOURCES

Scientific education resources are a crucial guarantee for the high-quality development of the science education system. With the advancement of digitalization, informatization, and globalization, the supply of scientific education resources is showing new trends of diversification, openness, and intelligence. International experience shows that the supply model of scientific education resources not only involves the coordinated development of multiple providers but also includes the diversification of resource content, the systematic development of platforms, and the continuous optimization of resource application and sharing mechanisms. The construction of this resource ecosystem directly impacts the fairness, effectiveness, and sustainability of science education.

3.1 Supply Entities: Diverse Collaboration Among Government, Society, and Learning

The main providers of scientific education resources are no longer limited to a single government or school, but have formed an ecosystem of "government-led, multi-party participation, and collaborative construction." Government departments still play a core role in policy and financial support, funding scientific education projects by establishing foundations. For example, the National Science Foundation (NSF) of the United States continues to fund scientific education projects and provide high-quality digital teaching resources for teachers and students [11]. The German Federal Ministry of Education and Research (BMBF) supports teachers' professional development and resource integration through the "Lehrer-Online" platform [12]. At the same time, non-profit organizations and foundations have become important supplementary forces. For example, STEM Learning in the UK is committed to providing digital educational resources and training courses for teachers. OpenSciEd, a non-profit organization supported by the Bill and Melinda Gates Foundation in the United States, develops and provides free three-dimensional science generative teaching materials that meet the NGSS standards, and promotes phenomenon-driven teaching methods. Technology companies and educational technology companies have also gradually become an important part of the resource ecosystem. For example, Khan Academy provides free online courses and educational resources, Canadian companies such as SMART Technologies develop interactive digital educational hardware and software tools, and Australia's CSIRO Science Institute promotes the "STEM in Schools" project to provide schools with professional digital STEM resources. Schools use online platforms and digital technologies to provide students with learning tools such as virtual laboratories and online courses, which is the "last mile" connecting resources and students. For example, some schools in Finland and Canada provide students with learning experiences such as virtual laboratories and online courses by establishing online teaching platforms.

3.2 Supply Content: Development and Application of Digital Resources

International science education resources are shifting from traditional static knowledge carriers to dynamic, interactive, and immersive learning experiences. Open digital textbooks have become a key development direction for international science education resources. For example, the US-based OpenStax project offers a series of free science textbooks covering subjects such as physics, chemistry, and biology, providing students with high-quality educational resources. Video resources are a visual and engaging teaching resource. They present scientific knowledge and experimental procedures through videos, enabling students to understand and learn more intuitively. They can be used in class or during independent learning. For example, France's CLEMI TV sparks students' curiosity by offering a variety of science education videos. India's Mocomi website provides animated reading content in biology, chemistry, physics, and other fields for children aged 4-12.

Virtual laboratories and interactive simulations provide students with repeatable, low-cost, and highly safe experimental experiences, effectively solving the problem of insufficient experimental conditions in some schools. The virtual laboratory platform provided by Labster in New Zealand allows students to conduct experiments in a safe environment and explore various scientific concepts and principles without the need for real laboratory equipment and materials. This form of resource greatly expands students' experimental experience and learning opportunities. The PhET interactive simulation project developed by the University of Colorado and funded by NSF provides simulation software covering elementary school to university, helping students to intuitively understand abstract concepts [13]. Studies have shown that the use of virtual experiments can significantly improve student grades and course pass rates. In addition, some countries use scientific adventure games, immersive situational simulations, VR and AR experiments to enhance students' learning interest and motivation. For example, the Smithsonian Institution Museum in the United States uses AR technology to build "virtual adventures" to allow students to learn scientific knowledge in an immersive environment. NASA's "Climate Kids" project helps students understand climate change through games and animations.

3.3 Supply Platform: Open and Shared Online Learning Center

To effectively integrate and distribute massive resources, various online platforms have emerged. These serve not only as resource repositories but also as comprehensive service centers integrating teaching support, professional development, and interactive communication. Resource supply platforms focus on providing teachers with teaching tools and professional development resources. The US-based Teaching Channel offers a wealth of instructional videos, curriculum design examples, and teaching strategies to help teachers improve their classroom practices. Canada's SMART Notebook interactive whiteboard software provides a wealth of science education resources and tools, including virtual labs, animated demonstrations, and lesson templates, helping teachers design engaging science lessons and engage students in interactive learning. Meanwhile, many institutions have established dedicated educational websites for specific scientific fields. For example, the US Geological Survey (USGS) created the "Earthquakes for Kids" website, which not only provides information about earthquakes but also features a Q&A session where students can ask geologists questions directly. Some platforms connect with museums and research institutions to promote the integration of learning resources within and outside of schools. For example, the European "Scientix" platform serves not only schools but also scientific research institutions, museums, and science centers, fostering cross-sector educational collaboration. In addition, some online learning platforms provide one-stop resource sharing services, bringing together high-quality resources from different regions and institutions, and realizing the sharing and exchange of cross-border educational resources.

4 COLLABORATIVE PRACTICE BETWEEN SCHOOL AND INFORMAL SCIENCE EDUCATION

In promoting scientific literacy, synergy between school-based education and informal learning spaces is widely considered a key path to enhancing the depth, breadth, and authenticity of learning. Research on informal science education shows that learning is a process that relies on individual motivation, social interaction, and context. The "free-choice learning" offered by museums and science centers emphasizes intrinsic motivation and deep engagement within highly customized contexts. This experiential nature helps foster a scientific interest and identity. Informal spaces, with their authentic contexts, diverse resources, and experiential nature, complement and extend the limitations of the school classroom. On the other hand, school-based education, with its core focus on systematic curriculum and emphasis on knowledge systematization and academic assessment, provides an institutionalized pathway for transforming the effectiveness of informal learning. International experience suggests that the integration of formal and informal learning is becoming a key trend in science education, truly transforming "interest" into "competence."

4.1 School Laboratory Environment: The "Hard" Support for Practical Learning

Science experimentation is a core component of science education. Developed countries attach great importance to providing students with safe, advanced, and inquiry-based experimental environments. Primary and secondary schools in countries like the United States, the United Kingdom, and Singapore are widely equipped with modern laboratories that adhere to strict safety standards. These laboratories serve not only as venues for validating knowledge but also as innovative spaces for students to raise questions, design experiments, collect evidence, and conduct argumentation. Furthermore, some countries are promoting the integration of virtual and real-world experiments. For example, some schools in Germany and Finland are using virtual laboratories and online platforms to expand students' inquiry experiences. Virtual experiments are an effective supplement to resource constraints or when experiments present safety risks. The quality and effectiveness of a school's science laboratory environment are directly related to the quality and effectiveness of experimental teaching.

4.2 Off-Campus Extension: Science and Technology Venues Promote In-Depth Learning Experience

Informal education venues, such as science museums, science centers, and natural history museums, have become an important extension of science education. International research shows that science centers and museums can significantly enhance the public's understanding and interest in science, especially in popularizing scientific knowledge and stimulating the innovative potential of young people [14]. The Exploratorium in San Francisco, USA, emphasizes the participation methods of "hands-on" and "thinking", and provides students and the public with immersive science learning experiences through interactive exhibitions and online resources. The Science Museum in London, UK, regularly holds experimental performances and science lectures for primary and secondary school students, and provides teaching support to teachers through the museum-school cooperation model. The Singapore Science Center is closely connected with the school curriculum, introducing rich resources into the school classroom, enhancing the practicality of the curriculum, and promoting the integration of classroom applications and off-campus resources. The Finnish Museum of Natural History provides students with online exploration tasks through virtual reality technology, realizing interdisciplinary and remote learning methods. The venue resources meet the scientific education needs of learners at different stages through museum-school integration, family and group learning, and individual visit experiences. These venue practices show that the educational function of science and technology venues has shifted from traditional exhibit displays to dynamic, learner-centered educational experience spaces.

4.3 Home-School-Community Collaboration: Building a Borderless Learning Environment

Science learning is not limited to schools and museums; families and communities are important learning venues. In recent years, more and more countries have advocated for collaboration between families, schools, and communities to jointly promote the improvement of young people's scientific literacy. For example, the American Museum of Natural History in New York launched the "Urban Advantage" project [15], providing guidance manuals and extracurricular resources for families and communities to help students better conduct scientific inquiry learning. Treating the community as a classroom and building a model of collaborative education between home, school, and community is an important manifestation of the socialization of science education. The Teton Science School in Wyoming, USA, proposed the concept of "community as classroom", using the local natural environment and expert resources to support student learning. At the same time, community art and environmental protection projects have also been incorporated into science education. For example, Philadelphia's public art mural project guides residents to understand local ecosystems and environmental protection by painting ecological-related murals and combining QR code technology. Enterprises and social organizations also play a role, such as the International Science and Engineering Fair (ISEF) hosted by the American Association for the Advancement of Science (AAAS), which provides a scientific research practice and display platform for young people around the world. These diversified collaborations have gradually enabled science education to move towards "borderless learning" and achieved in-depth linkage between education inside and outside the school.

5 EXPERIENCE SUMMARY AND ENLIGHTENMENT OF INTERNATIONAL SCIENCE EDUCATION

5.1 Summary of International Experience

Overall, the successful experiences of international science education all point to a systematic, open, and integrated development paradigm. At the macro level, countries are implementing top-level design through forward-looking national strategies and core competency-oriented curriculum reforms, emphasizing interdisciplinary integration and inquiry-based curriculum reform. At the meso level, they are prioritizing digitalization and open resource development, promoting the widespread use of virtual experiments, simulation platforms, and open textbooks. An open digital resource ecosystem, collaboratively built by diverse stakeholders including government, society, and the market, provides sustained momentum for educational innovation. At the micro level, they are breaking down school walls, emphasizing collaboration between schools and informal education venues, expanding learning spaces through museums, science and technology museums, and community projects, and building borderless learning communities, greatly enriching students' learning experiences and practical opportunities. By deeply analyzing the current status and development trends of international science education, we can draw valuable insights and provide powerful references for the digital development of science education in my country.

5.2 Implications for the Development of Science Education in China

5.2.1 Strengthen top-level design and systematically build an integrated curriculum and evaluation system

International experience shows that curriculum reform centered on scientific literacy is key to the sustainable development of science education. my country should further strengthen top-level design at the national level, incorporate science education into educational modernization and national innovation and development strategies, and build an integrated curriculum system that connects preschool through high school and integrates across disciplines. This requires not only the continued deepening of STEM/STEAM interdisciplinary educational concepts within curriculum standards, but also the development of detailed curriculum implementation guidelines and extensive teaching case studies to provide clear guidance for frontline teachers on how to effectively implement project-based learning and inquiry-based practice. At the same time, fundamental reforms in educational evaluation must be accelerated, focusing not only on knowledge acquisition but also on scientific practical skills, collaboration, innovation awareness, and social responsibility. A comprehensive evaluation system should be established to accurately measure students, thereby achieving an integrated "teaching-learning-evaluation" education model.

5.2.2 Build a scientific education cloud platform to create an open and collaborative high-quality resource ecosystem

High-quality resources are the foundation for the balanced development of science education. Drawing on international experience, my country should accelerate the construction of national and provincial science education cloud platforms to achieve centralized resource aggregation and intelligent distribution. Platform construction is more than simply a collection of resources; it also requires the establishment of a rigorous resource review mechanism to ensure the scientific nature, cutting-edge nature, and educational applicability of the content. At the same time, schools, teachers, research institutions, and businesses should be encouraged to participate in resource development, fostering an open, collaborative, and shared ecosystem of high-quality resources, providing teachers and students with a wealth of learning resources. Through resource co-construction and sharing, while improving the overall quality of science education resources, it can also effectively alleviate the imbalance in educational resources between regions and between urban and rural areas.

5.2.3 Innovate the teacher professional development model and build a multi-dimensional empowerment system

The key to teacher training in the digital age lies in online professional development and collaborative learning communities. International experience shows that teacher professional development has shifted from single training to continuous, practical, and networked. In the pre-service training stage, the competency standards for science teachers should be clarified, and interdisciplinary teaching design, digital teaching skills, and scientific inquiry guidance capabilities should be included in the core training objectives. In the post-service development stage, a hierarchical and classified training system with three levels of linkage between the national, local, and school levels should be established, and online professional learning communities, school-based training, and cross-school collective lesson preparation models should be vigorously promoted to promote peer assistance and collaborative growth among teachers. In addition, an evaluation and incentive mechanism related to teacher professional development should be established, and participation in training, resource development, and innovative practice should be linked to professional title promotion and remuneration, so as to promote the endogenous and normalized development of teachers.

5.2.4 Deepen the integration of in-school and out-of-school education and build a learning community that collaborates with families, schools, and communities

At the level of educational practice, the international community generally attaches importance to the combination of formal and informal learning. For my country, we should further promote the linkage of science education inside and outside the school, and build a learning community of "home-school-community collaboration". On the one hand, schools should take the initiative to cooperate with science and technology museums, museums, and research institutes to incorporate social education resources into the curriculum system to achieve integration inside and outside the classroom. On the other hand, through science festivals, community projects, and parent-child exploration activities, families and communities should be introduced into science education, guiding parents to become the "first mentors" of their children's scientific exploration, and forming a scientific education atmosphere where everyone participates and learns everywhere. This cross-border collaboration between home, school, and community can not only expand students' learning space, but also deeply embed science education into real-life situations, effectively promoting the comprehensive improvement of young people's scientific literacy.

6 CONCLUSION

Against the backdrop of increasingly fierce global scientific and technological competition, science education has become a strategic project crucial to a nation's future. This study, through a comparative analysis of the policy frameworks, resource ecosystems, and practical approaches of several leading science education countries, reveals the strategic, digital, and socialized trends in contemporary science education reform. The study finds that a successful science education system must be an integrated, coordinated whole, encompassing top-level design, resource provision, and practical innovation. For my country, efforts must focus on the following areas: First, strengthen top-level design, systematically construct a competency-based, integrated curriculum and assessment system, and promote the alignment of science education with the national innovation strategy; second, foster an open and collaborative ecosystem of high-quality resources to mitigate regional disparities and achieve educational equity; third, innovate teacher professional development models, establishing a multi-dimensional empowerment system that integrates online and offline learning, prioritizing both school-based and online learning, and enhancing teachers' interdisciplinary and digital teaching capabilities; fourth, deepen the integration of in-school and out-of-school education, promoting the joint participation of schools, families, and communities in science education, and building a borderless learning ecosystem.
The development of science education must grasp global trends while also grounded in local realities. Each initiative requires long-term strategic focus, sustained resource investment, and meticulous implementation. Only through the coordinated promotion of policies, resources, teachers, technology, and the environment can we truly achieve inclusive, equitable, and innovative science education. Building a high-quality, future-oriented science education system will truly inspire every child's curiosity and creativity, laying a solid foundation for cultivating a generation of young people with a scientific spirit, innovative capabilities, and a sense of social responsibility.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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PATHWAYS AND STRATEGIES FOR PROMOTING THE SHARING OF HIGH-QUALITY EDUCATIONAL RESOURCES IN SMALL RURAL SCHOOLS IN WESTERN REGIONS THROUGH THE "INTERNET PLUS" INITIATIVE

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Abstract: Against the backdrop of the "Internet Plus" era, small-scale rural schools in western regions face numerous developmental challenges that constrain progress in educational equity and quality. This paper explores pathways for promoting the sharing of high-quality educational resources among these schools through internet technology. Considering the current state of rural small-scale schools, a collaborative advancement pathway is proposed. This framework centres on an internet-based educational platform as the hub, with digital and intellectual educational resources as the primary providers. It utilises the "Three Classrooms" initiative and AI platform tools as delivery vehicles to achieve cross-regional sharing of high-quality resources. Feasible strategies are outlined across policy funding guarantees, teacher training, home-school collaboration, and exemplary leadership. These measures aim to promote the balanced allocation of urban-rural educational resources, thereby supporting small-scale rural schools in the west to achieve high-quality development characterised by being "small yet excellent".
Keyword: Internet plus; Rural small-scale schools; Digital educational resources; Intellectual educational resources; Resource sharing

1 INTRODUCTION

Education is a matter of national importance and a priority for the Party. In the grand journey towards the great rejuvenation of the Chinese nation, educational modernisation carries the hopes for national revitalisation and shoulders the vital mission of cultivating talent. It serves as the foundational project and strategic vanguard for national modernisation, with the modernisation of rural education being an indispensable key component. Due to geographical, economic and other factors, the development of education in rural areas has been constrained, becoming a significant shortfall in achieving educational modernisation. Modernising rural education is both an imperative for educational equity and justice, and a cornerstone for advancing the rural revitalisation strategy. The essence of educational modernisation extends beyond the renewal of physical infrastructure, teaching methods, and curriculum content; it fundamentally involves reconstructing a people-centred educational philosophy and substantially expanding equitable access to learning opportunities. For vast rural areas, educational modernisation signifies bridging the urban-rural knowledge divide, granting rural children equal developmental starting points and capacity reserves, and breaking the intergenerational transmission of poverty. This empowers them to become genuine builders and beneficiaries of rural revitalisation. Advancing rural educational modernisation is the essential pathway to resolving urban-rural development imbalances and promoting social equity.

Small-scale schools (village primary schools and teaching points with fewer than 100 pupils) serve as the nerve endings of the rural education system. They play a unique and irreplaceable role in safeguarding equitable access to education, preserving rural cultural heritage, and serving rural communities. These institutions bear the crucial responsibility of providing foundational education as a safety net for the most remote and disadvantaged populations. Effectively managing small-scale schools is a vital task in implementing the strategy of revitalising the nation through science and education and accelerating educational modernisation. It is a fundamental requirement for executing the rural revitalisation strategy and advancing the equalisation of basic public services between urban and rural areas. Furthermore, it constitutes a powerful measure for winning the battle against educational poverty and comprehensively building a moderately prosperous society[1]. The healthy development of rural small-scale schools is an essential requirement for modernising rural education by "establishing a safety net, addressing shortcomings, and promoting equity." It constitutes the institutional safeguard for fulfilling the educational commitment that "no child shall be left behind." Without the modernisation of rural small-scale schools, there can be no genuine modernisation of rural education. Neglecting the development of small-scale schools would leave the edifice of educational modernisation without a solid foundation. Successfully managing small-scale schools in western rural areas can collectively sustain the "root system" ecology of China's rural education[2].

However, the stark reality cannot be overlooked: small-scale schools are mired in multiple developmental challenges on their journey towards modernisation, facing the severe predicaments of being "small and weak" and "small and substandard". The persistent shortage of high-quality teaching staff constitutes the primary bottleneck, with small schools enduring the long-standing dilemma of teachers being "unwilling to take up posts, unable to be retained, and incapable of delivering effective teaching". Structural staffing shortages are particularly acute, while the singularity and low quality of curriculum resources further undermine teaching standards. Although educational informatisation initiatives have been rolled out, they commonly suffer from the awkward predicament of "prioritising hardware over application," "abundant resources but low efficiency," and "network connectivity without integration." Many schools possess basic digital equipment, yet lack corresponding high-quality digital educational resources. Teachers' IT application skills remain inadequate, and the deep integration of information technology with subject teaching is virtually non-existent. These intertwined issues make the modernisation journey of rural small-scale schools exceedingly arduous.

Breaking through resource constraints and achieving the sharing of high-quality educational resources has become the path to modernisation for small-scale schools. Sharing high-quality educational resources refers to utilising information technology to overcome temporal and spatial limitations and resource barriers, thereby precisely delivering resources such as teaching staff, curricula, teaching methodologies, and management expertise from high-quality urban schools and educational institutions to rural small-scale schools. This facilitates the optimal allocation and efficient utilisation of resources. Its significance manifests across three dimensions: firstly, addressing resource deficits to achieve balanced educational provision; secondly, empowering teacher development to stimulate intrinsic teaching motivation; thirdly, driving pedagogical innovation to foster holistic student development. Sharing high-quality resources represents a crucial pathway to resolving the developmental challenges faced by small-scale schools. It is also an imperative of our era for promoting educational equity, enhancing educational quality, and serving rural revitalisation. This approach enables such schools to deliver quality education with a human touch despite resource constraints, thereby achieving the developmental goals of being "small yet excellent" and "small yet beautiful".

Sharing signifies breaking down barriers of time and space. Today, the rapid advancement of information technology and the deepening implementation of the "Internet Plus" strategy provide robust support for sharing high-quality educational resources. The rise of "Internet Plus" has become a significant force in promoting balanced educational development. To achieve genuine equilibrium in education, effective pathways and strategies must be established to fully leverage the advantages of "Internet Plus". This will facilitate equitable access to educational resources, enhance the quality of education in small-scale rural schools in western regions, and create a favourable educational environment for the growth and development of rural students. The ultimate aim is to ensure every child enjoys equitable and high-quality education. How to leverage "Internet Plus" to overcome temporal and spatial barriers and construct effective pathways for sharing high-quality educational resources has become the pivotal challenge in addressing the imbalance in rural education development in western China.

2 THE CURRENT STATE OF EDUCATION IN SMALL RURAL SCHOOLS IN WESTERN REGIONS

The lagging state of education in small-scale rural schools in western regions not only impedes the future development of rural students but also constrains the comprehensive progress of rural society, representing a critical shortfall in the modernisation of education. Addressing this shortfall to ensure every rural child enjoys equitable and quality education has become a critical challenge that the education sector must confront and resolve. It also represents an urgent issue on the path towards educational equity and balanced development. Though small in scale, these schools bear the hopes of rural education and serve as vital strongholds in breaking the cycle of intergenerational poverty. Consequently, the educational development of small-scale rural schools in western regions demands high priority. The current state of education in these rural small-scale schools is detailed in Table 1.

Table 1 The Current State of Education in Small Rural Schools

Summary of Educational Issues	Specific manifestations
Infrastructure is lagging behind[3]	Teaching facilities are outdated, lacking modern equipment, with insufficient functional spaces and inadequate conditions for multimedia and laboratories; living facilities are substandard, with poor canteen and dormitory conditions; sports facilities are inadequate, with insufficient playing fields and equipment; network infrastructure is lagging.
Insufficient teaching staff[4]	There is a shortage of teaching staff, with an imbalanced structure and varying levels of professional competence. There is a significant exodus of outstanding teachers, difficulties in recruiting new teachers, and instability within the teaching workforce. Opportunities for teacher training are scarce, knowledge updates are slow, and teachers' information literacy remains low.
Student intake is of poor quality[5]	Due to family circumstances and economic constraints, the dropout rate remains high; Many pupils hail from disadvantaged backgrounds with weak foundational learning skills; Students exhibit insufficient motivation and lack clear objectives; Poor study habits and attitudes prevail, accompanied by a general aversion to learning.
Shortage of teaching resources[6]	Textbooks and supplementary teaching materials are scarce and not updated promptly; library resources are insufficient, affecting reading opportunities; resources for social practice are limited, making it difficult to organise practical activities; online course resources are challenging to utilise effectively.
Inadequate educational management[7]	Management team capabilities are limited, and management systems are inadequate; teaching supervision and evaluation mechanisms are lacking; home-school collaboration and community involvement are insufficient; and levels of information management are low.

2.1 Infrastructure is Lagging Behind

Rural small-scale schools commonly suffer from inadequate infrastructure, which directly impedes the normal conduct of teaching activities and represents a systemic shortfall in their operational conditions. This infrastructure deficit not only exacerbates the educational disparity between urban and rural areas but also places pupils at a disadvantage from the outset due to resource scarcity, thereby widening the persistent digital divide between urban and rural communities.

2.2 Insufficient Teaching Staff

The shortage of qualified teachers remains a persistent challenge that fundamentally constrains the development of rural education. Small school sizes, remote locations, and harsh living conditions make it difficult to attract sufficient teachers to these areas. It is imperative to establish a comprehensive professional development support system tailored to the realities of rural education. This system must be designed with a systematic and holistic approach to professional growth, spanning the entire career trajectory of teachers, thereby providing robust support for the professional advancement of educators in small rural schools.

2.3 Student Intake is of Poor Quality

The quality of student enrollment in small rural schools is influenced by multiple factors, exhibiting distinct weaknesses. The low quality of students not only increases teaching challenges for educators but also leads to persistently low overall graduation rates, creating a vicious cycle.

2.4 Shortage of Teaching Resources

The shortage of teaching resources has a direct and significant impact on students' learning experiences and skill development, limiting their comprehensive growth.

2.5 Inadequate Educational Management

The inefficiency of school management has hindered the standardized development of schools and the improvement of educational quality. It not only affects daily operations but also leaves schools ill-equipped to handle emergencies, thereby impeding their modernization efforts.

3 PATHWAYS FOR RURAL SMALL-SCALE SCHOOLS TO SHARE HIGH-QUALITY EDUCATIONAL RESOURCES BASED ON "INTERNET PLUS"

The development of internet technology has brought profound changes to the field of education, with its impact being particularly significant in small rural schools where educational resources are relatively scarce. Through the internet, these schools can directly access high-quality teaching expertise and abundant educational resources, thereby mitigating to some extent the imbalances inherent in traditional resource allocation. However, despite the internet's immense advantages in information transmission and resource sharing, it cannot directly improve a school's infrastructure, student quality, or educational management systems. Therefore, internet-based educational resource sharing primarily focuses on two aspects: teaching resources and instructional resources. This has formed a "1+2+3+N" resource-sharing pathway, namely "one platform, two types of resources, three types of classrooms, and N tools." The specific pathway model is shown in Figure 1.

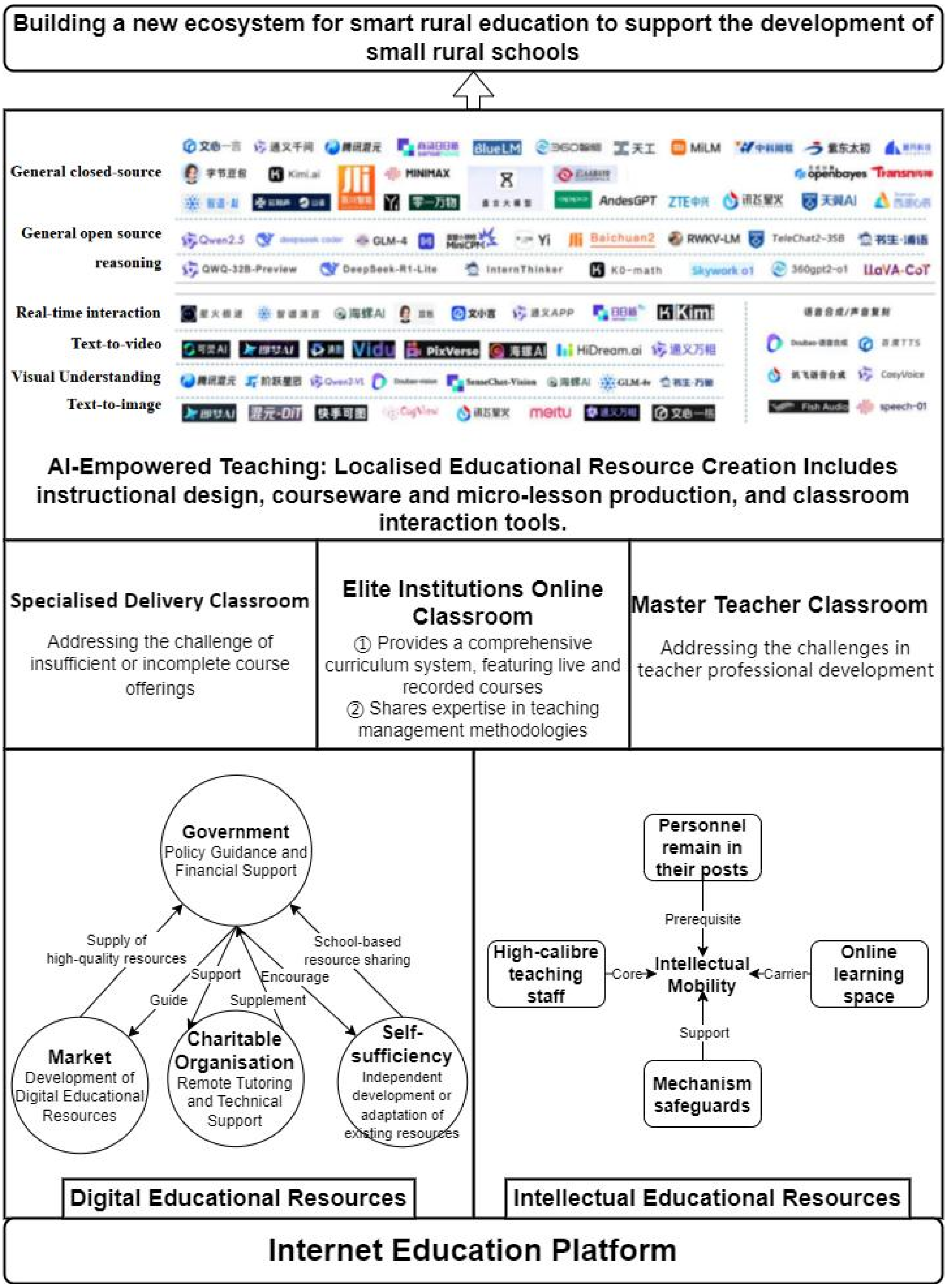

Figure 1 Pathways for Small Rural Schools in Western Regions to Share Educational Resources Through the Internet

3.1 One Platform (Internet Education Platform): A Hub for Providing High-Quality Educational Resources

Internet education platforms are reshaping the educational ecosystem through digital technology, enabling high-quality educational resources to bridge geographical divides and reach broader audiences. They have become a key force driving educational modernization and universal access. The Outline of the National Education Development Plan (2024–2035) explicitly calls for strengthening and effectively utilizing the National Smart Education Public Service Platform[8]. Taking the National Smart Education Platform for Primary and Secondary Schools as an example, it serves as the core vehicle for the education digitization strategy. By integrating high-quality platform resources at all levels and providing systematic resource supply with precise service matching, it offers crucial support for addressing the resource gap in rural small-scale schools. The platform consolidates high-quality course resources across all subjects and grade levels in basic education, encompassing multimodal content such as classroom recordings, micro-lecture videos, interactive exercises, and virtual experiments. It features resources across 12 sections including moral education, curriculum instruction, physical education, aesthetic education, and labor education. Its core value lies in transforming the teaching excellence of urban schools into accessible learning materials for rural students. Particularly valuable are the platform's extensive resources of audio-visual teaching videos and courseware for physical education, music, and art, enabling these subjects to re-enter rural classrooms. Additionally, the Teacher Professional Development section of the National Smart Education Platform for Primary and Secondary Schools provides rural educators with abundant learning resources. This section encompasses various training content, including ideological and political education, teacher ethics, general knowledge development, and subject-specific training, allowing teachers to pursue self-directed learning based on their individual needs. Furthermore, the platform facilitates online communication and collaboration among teachers. Rural educators can engage with peers from other regions to discuss teaching challenges, share pedagogical insights, and continuously enhance their professional competence through these exchanges.

Centered on the National Smart Education Platform for Primary and Secondary Schools, supplemented by other high-quality platforms at various levels, a comprehensive digital educational resource repository covering all subjects and grade levels has been established. This initiative effectively alleviates long-standing structural challenges in rural areas, such as resource scarcity, teacher shortages, and incomplete curriculum offerings. Each platform also features robust interactive capabilities, supporting teacher collaboration and discussion as well as interactive classroom instruction, thereby providing strong foundational support for future resource-sharing models.

3.2 Two Types of Resources: Digital Educational Resources and Intellectual Educational Resources

3.2.1 Digital educational resource sharing

Digital educational resources refer to a collection of resources specifically designed and developed to achieve educational objectives, digitally processed, and capable of operating within an information-based environment to serve teaching and learning activities[9]. The provision of digital educational resources encompasses four dimensions: government supply, market supply, public welfare supply, and self-supply[10]. By integrating these four supply models, a comprehensive, efficient, and sustainable pathway can be established for rural small-scale schools to share high-quality educational resources.

First, the government should take the lead by establishing a foundational framework for digital educational resources in rural small-scale schools through policy guidance and financial support. This includes investing in high-speed, stable network infrastructure to ensure every school has internet access, thereby providing the hardware foundation for transmitting digital educational resources. Simultaneously, the government should develop or procure a set of fundamental, widely applicable digital educational resources and provide them free of charge to rural small-scale schools, ensuring their basic educational resource needs are met. Second, market mechanisms should be introduced to encourage enterprises and social forces to participate in building rural digital educational resources. Incentives such as tax breaks and financial subsidies should attract education technology companies and publishers to develop digital educational resources tailored to the characteristics of rural small-scale schools, meeting the diverse learning needs of students. Simultaneously, introducing market competition mechanisms will enhance the effective circulation and sharing of resources, driving continuous improvements in resource quality. The public welfare supply model also plays a vital role in promoting the sharing of high-quality educational resources among rural small-scale schools. Non-profit organizations and individuals can develop targeted digital educational resources addressing the unique needs of rural education and make them freely accessible to the public. Public welfare organizations can also regularly organize volunteer teams to provide remote teaching guidance and technical support to rural small-scale schools, helping teachers and students better utilize digital educational resources. Finally, rural small-scale schools should be encouraged to engage in self-supply, enhancing their capacity for school-based resource development. Schools can independently develop or adapt existing resources based on their actual conditions and the needs of teachers and students, forming distinctive school-based digital educational resource repositories. This not only meets the personalized teaching needs of schools but also stimulates the creativity and enthusiasm of teachers and students. Schools can also establish resource-sharing mechanisms among themselves, utilizing technological means such as cloud platforms to achieve mutual exchange of resources and collective improvement.

The sharing of digital educational resources, through the synergistic effects of four supply models, has brought positive impacts to small-scale rural schools in western China in terms of resource access, teaching quality improvement, and teacher-student development. It effectively promotes the educational advancement of these schools. Not only does it address the shortage of educational resources in these institutions, but it also enhances teaching quality, narrows the urban-rural educational gap, and makes significant contributions to achieving educational equity and modernization. Digital educational resources will serve as a fulcrum for revitalizing education in rural western regions, propelling urban-rural educational development toward greater balance and quality while advancing the realization of educational equity.

3.2.2 Intellectual educational resource sharing

Intellectual educational resources refer to individuals, groups, or organizations within and outside the education sector possessing strong information literacy and knowledge creation capabilities, engaged in high-intellectual activities such as knowledge creation and problem-solving. However, only those that tangibly generate social and educational benefits through intellectual activities can be termed intellectual resources[11]. The sharing of intellectual educational resources entails the shared utilization of their educational, economic, and social value. The sharing of intellectual educational resources can be advanced through intellectual mobility. This approach involves leveraging mobile internet, big data, cloud platforms, and other information technologies alongside sound policy mechanisms to overcome the constraints of teachers being tied to specific schools. It aggregates the intellectual services of high-quality educators within a networked space, making them accessible to teachers and students in under-resourced schools. This model comprises four core elements: maintaining the teacher-position relationship, utilizing high-quality faculty, establishing networked learning spaces, and implementing institutional safeguards[12]. Intellectual mobility, as a novel form of teacher mobility, offers fresh perspectives and pathways to address the scarcity of quality educational resources in small rural schools in China's western regions. By sharing the intellectual services of high-quality teachers with underprivileged schools through information technology while maintaining their original positions, this approach can effectively alleviate regional imbalances in educational development.

The "intellectual mobility without physical relocation" is the defining characteristic that distinguishes intellectual mobility from traditional teacher rotation. This approach avoids disrupting the teaching order at the original institution caused by the physical movement of high-quality teaching staff, while simultaneously enabling the cross-regional transfer of intellectual resources through institutional design. Establishing an "Intellectual Mobility Teacher Talent Pool" will recruit key teachers and subject leaders from high-quality schools in developed eastern regions and western cities. These educators will regularly provide online teaching research and curriculum guidance services to rural schools while retaining their personnel status, professional title evaluations, and performance-based wages with their original institutions. This approach alleviates their concerns, safeguards career stability, and enables flexible intellectual resource deployment. The core of intellectual mobility lies in sharing high-quality teaching talent. High-quality intellectual resources are a critical prerequisite for advancing the development of small-scale rural schools in western regions. Through intellectual mobility, outstanding teachers—including core educators and subject leaders from urban elite schools—can transmit their pedagogical philosophies, methodologies, and experiences to rural teachers and students in western areas via online learning spaces. This guidance helps rural educators refine teaching approaches and assists students in overcoming learning challenges. This model not only elevates student academic performance but also provides professional development opportunities for local teachers, driving comprehensive improvements in educational quality. The core vehicle for intellectual mobility is the online learning space, which is essential for achieving cross-regional sharing of high-quality educational resources. For small-scale schools in rural western regions, establishing a unified online learning platform enables high-quality teachers to participate in rural school teaching processes in real-time or asynchronously. This "virtual presence" approach not only overcomes the limitations imposed by physical distance but also enhances teaching effectiveness and the learning experience for students. The effective implementation of intellectual mobility relies on robust institutional safeguards. Coordination mechanisms, constraint mechanisms, and incentive mechanisms form the three essential components of this safeguard. Coordination mechanisms ensure the normal, continuous, and stable operation of online learning spaces. Educational administrative departments, schools, technology providers, and other stakeholders must collaborate closely, clarify respective responsibilities, and jointly resolve issues encountered during the construction and operation of online learning spaces. Constraint mechanisms ensure the orderly operation of intellectual mobility and maximize its intended impact. During this process, teachers' sharing behaviors require regulation and oversight—for instance, establishing task lists and time requirements for teacher participation to ensure they complete teaching resource sharing, online tutoring, and other duties as stipulated. Simultaneously, establishing corresponding supervision and evaluation mechanisms allows for assessing and providing feedback on the effectiveness of teachers' sharing activities. This enables timely identification and correction of issues, ensuring the quality and impact of intellectual flow. Reward mechanisms serve as a crucial means to stimulate the enthusiasm of teachers, schools, and educational administrators in participating in intellectual flow. By establishing reasonable reward systems that provide both material and non-material incentives to teachers engaged in intellectual flow, the initiative for sharing can be enhanced. This fosters a positive incentive environment, driving the sustainable development of intellectual flow.

The flow of intellectual educational resources has broken through the traditional temporal and spatial boundaries of educational resource allocation by reconfiguring the logic of teacher resource allocation and institutional innovation. This has created the possibility for small-scale rural schools in western regions to "access quality education without leaving their hometowns." This represents not only a substantive advancement in educational equity but also a significant practice in modernizing the educational governance system in the digital economy era. It can effectively contribute to achieving the goals of rural revitalization and educational modernization.

3.3 "Three Classrooms": Pathways to Promote the Sharing of High-Quality Educational Resources

In 2020, the Ministry of Education issued the "Guiding Opinions on Strengthening the Application of the ‘Three Classrooms’," emphasizing the need to actively advance the development of "Internet Plus Education," promote the deep integration of information technology with educational practices, systematically implement the "Three Classrooms" initiative, and drive the realization of high-quality and balanced educational development[13]. The "Three Classrooms" initiative represents a key measure by the Ministry of Education to advance educational informatization and the sharing of high-quality educational resources. Its core objective is to bridge regional, urban-rural, and inter-school educational disparities through internet technology, thereby providing sustainable access to excellent teaching resources for small-scale schools in rural western regions.

3.3.1 Specialised delivery classroom: establishing a channel for course resource delivery to resolve the structural shortage of teaching staff

The "Specialised Delivery Classroom" initiative primarily addresses the challenges faced by under-resourced rural schools and teaching points in delivering the full range of state-mandated courses due to teacher shortages. It employs methods such as online specialised courses or synchronous teaching, alongside the internet to deliver appropriate, high-quality educational resources aligned with teaching schedules. This approach assists these institutions in fully implementing the required curriculum, thereby promoting educational equity and balanced development.

By leveraging internet technology, collaborative lesson planning between lead and receiving-end teachers enables the precise delivery of teaching resources, providing rural schools with high-quality curriculum materials. This creates synchronous classroom scenarios where urban elite schools and rural small-scale institutions conduct lessons concurrently. During these synchronous sessions, teachers and pupils from both locations engage in real-time interaction, jointly participating in classroom discussions and activities. Outstanding teachers from urban schools can deliver lessons to rural pupils via live video streaming, while also gaining insights into their learning progress and requirements to promptly adjust teaching methods and content. Teachers at rural schools assume a supporting role during synchronous sessions, aiding pupils in better understanding and mastering knowledge. This synchronous classroom model not only enables rural pupils to access high-quality teaching resources but also fosters exchange and collaboration between urban and rural educators, collectively elevating teaching standards.

3.3.2 Master teacher classroom: fostering professional development communities to enhance teachers' professional competence

The "Master Teacher Classroom" initiative primarily addresses the challenges of inadequate teaching capabilities and insufficient professional development among educators. By establishing online professional learning communities and leveraging the exemplary impact of distinguished teachers and their courses, it explores novel forms of teaching and research activities within digital environments. This approach enables outstanding educators to elevate the standards of their peers, facilitates broader sharing of master teacher resources, and ultimately fosters professional growth among teaching staff.

The core objective of the Master Teacher Classroom initiative is to foster the professional development of rural educators by sharing the teaching expertise of distinguished educators. This is achieved through establishing online professional learning communities to advance the professional growth of rural teachers. The Master Teacher Classroom must transcend mere participation in or observation of teaching research and instruction. Under the guidance and mentorship of master teachers, it should facilitate practical engagement in research projects, with particular emphasis on enhancing rural teachers' capacity for developing local curricula. This approach will ultimately strengthen the cultural confidence of rural educators. Leveraging internet platforms, we organise joint online professional development activities for urban and rural teachers, enabling rural educators to directly access master teachers' experience sharing and learn advanced pedagogical concepts and methodologies. Through regular online exchanges and collaboration, we implement a "strengthening the weaker" approach to teacher development, fostering a positive atmosphere of mutual learning and collective progress among educators. This gradually narrows the professional capability gap between urban and rural teaching staff.

3.3.3 Elite institutions online classroom: fostering a resource-sharing ecosystem to drive systematic quality enhancement

The Elite Schools Online Classroom initiative addresses the pressing need to effectively narrow educational disparities across regions, urban-rural areas, and schools. Centred on high-performing institutions, it systematically and comprehensively facilitates the sharing of premium educational resources regionally or nationwide through online schools and courses. This approach meets students' demands for personalised development and high-quality education.

Promote in-depth collaboration between small rural schools and prestigious institutions to achieve customized sharing of educational resources. Tailored to the unique teaching environments and student needs of rural schools, leading institutions can dispatch core faculty to deliver remote instruction or conduct online training. Through cross-regional lesson observation, discussion, and collaborative seminars, this approach facilitates shared access to teaching expertise, accelerating professional growth among educators while providing personalized learning guidance for rural students. Simultaneously, rural schools can submit specific educational requests to prestigious institutions based on their unique circumstances. Through the "Elite School Online Classroom" platform, they gain access to customized educational resources, ensuring precise alignment and effective utilization of educational assets.

The "Three Classrooms" initiative establishes a multi-dimensional support system for revitalizing rural education in western China through functional complementarity, technological empowerment, and institutional innovation. By synergistically advancing these three classroom models, it not only effectively alleviates challenges faced by small-scale rural schools in western regions—such as teacher shortages, low teaching quality, and resource scarcity—but also provides a practical pathway to achieve educational equity and elevate overall educational standards.

3.4 "N Tools (AI Tools)": Engines for Localized Creation and Transformation of Educational Resources

The introduction of artificial intelligence technology has provided rural teachers with a new pathway to "Create—Adapt—Optimize" educational resources. AI tools not only lower the threshold for resource development but also help rural educators transform standardized platform resources into localized teaching content tailored to local students' cognitive characteristics, cultural backgrounds, and life experiences through intelligent adaptation, personalized generation, and data analysis. Rural areas possess unique cultural, geographical, and social environments. Rural teachers can leverage AI platform tools to create educational resources tailored to local realities. These personalized resources not only foster students' identification with local culture but also make teaching content more relevant to students' lives, sparking their interest in learning and enhancing learning outcomes. Simultaneously, as rural teachers utilize AI platform tools to create and adapt educational resources, their own capabilities are significantly enhanced, thereby promoting professional development and improving their information technology literacy.

The deployment of AI technology is not intended to replace teachers, but rather to provide supplementary tools for teaching and learning within small rural schools. The ultimate significance of empowering these institutions through AI platforms lies not in emulating urban educational standards, but in forging a path towards rural educational modernisation that remains rooted in its heritage—connecting to global knowledge systems while deeply embedding local cultural gene.

4 STRATEGIES TO FACILITATE SMALL-SCALE RURAL COMMUNITIES IN WESTERN REGIONS TO SHARE QUALITY EDUCATIONAL RESOURCES

4.1 Policy Funding Support—Prioritising the Development and Construction of Small-Scale Rural Schools in Western Regions

Policies and regulations serve as crucial safeguards for implementing the "Internet Plus" initiative in small rural schools in western regions, thereby facilitating the sharing of high-quality educational resources. Further clarify the importance of small rural schools within the broader education development framework, establishing their priority status in the allocation of educational resources. Implement differentiated policy support mechanisms tailored to the characteristics of small schools, providing special policy preferences in funding, resource development, teacher allocation, and assessment systems. This will provide a robust institutional foundation for school development, promote the balanced distribution of educational resources, and advance educational equity. Concurrently, a dedicated oversight mechanism should be established to strengthen policy monitoring and implementation, ensuring that all measures take root effectively. This will tangibly improve the operating conditions of small-scale schools, invigorate rural educational institutions, and enable rural children to access equitable, high-quality education.

In the process of enabling small-scale rural schools in western regions to share high-quality educational resources through the "Internet Plus" initiative, funding security stands as a pivotal factor and a prerequisite for the entire endeavour. Only with robust financial backing can subsequent resource development and application proceed smoothly. Local governments must increase financial investment in the educational informatisation of small-scale rural schools in western regions. This funding should support rural institutions in procuring information technology equipment, developing network infrastructure, and establishing platforms for high-quality educational resources. Strengthening foundational infrastructure will provide robust material support for these schools to access premium educational resources. The implementation and application of the "Three Classrooms" initiative and "Teacher Intellectual Mobility" programmes in rural small-scale schools will facilitate the seamless integration of high-quality educational resources into the classroom. This will inject vitality into the teaching and learning activities of small-scale schools, ensuring that rural children have access to the same learning resources and opportunities as their urban counterparts.

4.2 Teacher Training—Establishing a Training Framework to Enhance Teachers' Digital Literacy

A highly qualified teaching workforce constitutes the core driving force for the development of small-scale rural schools. Only through continuous enhancement of teachers' capabilities can superior educational services be provided to rural pupils. Tailored to the characteristics and needs of teachers in small-scale rural schools within western regions, multi-tiered and diverse training initiatives shall be implemented. Organise centralised training sessions, inviting specialists and experienced teachers to deliver digital-focused lectures and training courses for rural educators. This enables teachers to acquire fundamental digital teaching skills, better adapt to the demands of information-based instruction, and fully leverage high-quality educational resources to enhance classroom teaching quality.

4.3 Home-School Collaboration—Fostering a Synergistic Educational Approach to Stimulate Students' Intrinsic Motivation for Learning

The recipients of educational resources are pupils, and establishing home-school collaboration is a crucial element in enabling small-scale rural schools in western regions to share high-quality educational resources. Parental support and involvement can provide pupils with a conducive learning environment, stimulate their intrinsic motivation to learn, and promote the effective utilisation of educational resources. In rural western regions, family education concepts remain relatively outdated, with parents demonstrating lower levels of commitment and involvement in their children's education. Schools should proactively assume responsibility for guiding and instructing parents, disseminating scientific educational concepts and methodologies to enhance parental awareness and participation. Furthermore, parents should be encouraged to engage in school educational activities, enabling them to experience the educational process firsthand and thereby strengthening their sense of identification with and responsibility for education. Fostering a positive home-school collaboration fosters an uplifting learning environment for pupils, igniting their academic interest and initiative. This enables pupils to more fully utilise high-quality educational resources, enhances learning outcomes, and promotes their holistic physical and mental development.

4.4 Exemplary Leadership—Establishing a Benchmark Radiation System

Demonstration and leadership serve as the pivotal approach to resolving the predicament of underutilised and inefficient educational resources in rural areas. Its core lies in creating replicable and scalable exemplary cases, thereby catalysing the intrinsic momentum for regional resource sharing through targeted initiatives. Demonstration leadership transcends mere showcase displays; it involves systematically establishing a closed-loop mechanism of "pilot exploration – experience refinement – radiating dissemination". Through pioneering trials at exemplary institutions, it furnishes peer schools with comprehensible, learnable, and actionable practical paradigms. Its value lies not only in providing models for technological application but also in leveraging the successful practices of benchmark schools to elevate regional educational standards holistically, thereby forging a new educational ecosystem.
Adhering to the working principle of piloting first and exemplary leadership, we consistently pursue dual objectives of problem-solving and goal-achievement, striving to establish pilot demonstration schools with comprehensive coverage. Specifically, demonstration leadership must focus on three dimensions. Firstly, creating "Internet Plus Resource Sharing" demonstration schools. Selecting rural small-scale schools within the region that possess relatively well-developed infrastructure and teachers with higher levels of digital literacy as pilot sites, we will establish a standardised process of "resource input–localised adaptation–feedback on outcomes", providing tangible reference points for neighbouring schools. Secondly, distilling replicable localised practices. Demonstration schools must address the practical challenges faced by small rural schools in western regions – such as limited student numbers, insufficient teaching resources, and low educational standards – by summarising low-cost, easily implementable technical solutions, streamlined resource integration strategies, and pathways for enhancing teacher capabilities. These insights can be shared through case compilations, on-site observations, and short instructional videos to lower the learning threshold for other institutions. Thirdly, establishing a radiating influence system. The success of a single demonstration site is not the end goal; the key lies in stimulating regional-wide improvement. On one hand, establish demonstration and paired assistance mechanisms. Encourage demonstration schools to proactively "reach out" and form close-knit assistance communities with multiple underperforming village schools. Through online master teacher studios, cross-school mentor-apprentice pairings, regular teaching support (online/offline seminars), and shared school-based resource libraries, achieve precise and sustained knowledge transfer and experience dissemination. Secondly, strengthen regional coordination and policy safeguards. Local education authorities should act as organisers and facilitators, incorporating demonstration impact into school evaluations and headteacher assessments while establishing dedicated incentive funds. They should strategically plan the distribution of demonstration schools to prevent resource concentration and ensure balanced coverage. Concurrently, authorities must provide sustained technical support and professional development opportunities to maintain the demonstration schools' leading edge.

5 CONCLUSION

The "Internet Plus" initiative has opened up entirely new avenues for small rural schools in western regions to overcome constraints on educational resources. Its core value lies not merely in the technical delivery of resources, but in fundamentally reshaping the logic through which educational equity is achieved. It serves not only as an effective tool for bridging the urban-rural education divide, but also as a powerful engine driving the renewal of educational philosophies, the transformation of pedagogical models, and the restructuring of educational systems. From cloud-based classrooms breaking geographical barriers, to smart platforms integrating high-calibre teaching resources, and digital resource libraries bridging curriculum gaps, the educational divide is gradually being narrowed by digital technology. We must maintain a clear understanding that technology is a means, while nurturing talent remains the ultimate goal. Seizing this historic opportunity, we should deepen the integrated application of "Internet Plus Education" with greater resolve and more concrete measures. Continuously refining the ecosystem for resource sharing will enable every small rural school to set sail amidst the waves of the information age, ensuring every rural child accesses equitable, high-quality education. This will lay a solid foundation of talent for rural revitalisation and the nation's future development.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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