International Journal of Secondary Education
2026, Vol. 14, No. 1, pp. 43–55
https://doi.org/10.11648/j.ijsedu.20261401.15

Research Article

Analysis of the Application Status and Development Path of Artificial Intelligence in High School Biology Experiment Teaching

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Abstract

The rapid advancement of artificial intelligence (AI) technologies has led to their increasing integration into education. High school biology experimental teaching, a critical component in cultivating students' scientific literacy, is gradually investigating deeper integration with AI. This research reviews the theoretical foundations of AI in education and delineates the essential connotations of high school biology experimentation, offering a systematic analysis of the current application of AI technologies in basic education, with a focus on biology labs. Utilizing questionnaire data from teachers and students at a key high school in Zhengzhou, the research uncovers the actual adoption rate, implementation forms, and influences of AI on teaching efficiency, student comprehension, and laboratory safety. The results suggest that while certain schools have begun adopting AI-assisted tools such as virtual simulations and intelligent feedback systems, they still face considerable challenges in technological integration, infrastructure, teacher competency, and pedagogical adaptability. To tackle these challenges, this paper introduces innovative teaching models supported by AI, such as AI-driven virtual experiments and personalized learning support, and highlights the importance of sustainable professional development programs to improve biology teachers' AI literacy and technical support mechanisms. The research provides theoretical insights and practical approaches for the high-quality, sustainable application of AI in high school biology experimental instruction, thereby advancing the intelligent transformation of science education.

Keywords

High School Biology Experiment Teaching, Artificial Intelligence, Application Status, Cognitive Development Pathways, Teaching Model Innovation, Teacher Professional Development, Intelligent Education

1. Introduction

1.1. Research Background and Significance

As the Fourth Industrial Revolution progresses, Artificial Intelligence (AI), a pivotal force in the digital and intelligent era, is transforming the education ecosystem at an unprecedented speed [1]. In particular, AI technologies in science education, using data-driven strategies, intelligent modeling, and adaptive learning mechanisms, provide innovative avenues for enhancing precision and personalization in experimental

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Received: 20 January 2026; **Accepted:** 30 January 2026; **Published:** 9 February 2026

teaching. High school biology experiments, essential for fostering students' scientific inquiry skills and empirical thinking, have historically faced limitations due to poor experimental conditions, low operational safety, inaccurate data collection, and uneven student engagement [2]. Traditional teaching models fall short in fulfilling the advanced requirements for core competencies such as "scientific thinking" and "scientific inquiry" specified in the "General Senior High School Biology Curriculum Standards (2017 Edition, 2020 Revision)," highlighting the need for structural reforms through emerging technologies.

In this context, the emergence of generative AI has revitalized contextualized instructional design. For example, in the classic experiment "Investigating Factors Affecting Photosynthesis," teachers can utilize large language models to create multidimensional, cross-context hypothetical question chains, guiding students through predictive-verification thinking training and considerably improving their scientific reasoning abilities [3]. Meanwhile, AI-based virtual simulation platforms can replicate real-world changes in light intensity, CO_2 concentration, and other variables, overcoming the physical limitations of laboratory hardware to concretely illustrate abstract physiological mechanisms [2]. Furthermore, the integration of smart sensor networks with edge computing technology allows for millisecond-level dynamic capture of key parameters such as pH, dissolved oxygen, and light intensity during experiments, substantially enhancing the reliability and validity of data collection [4].

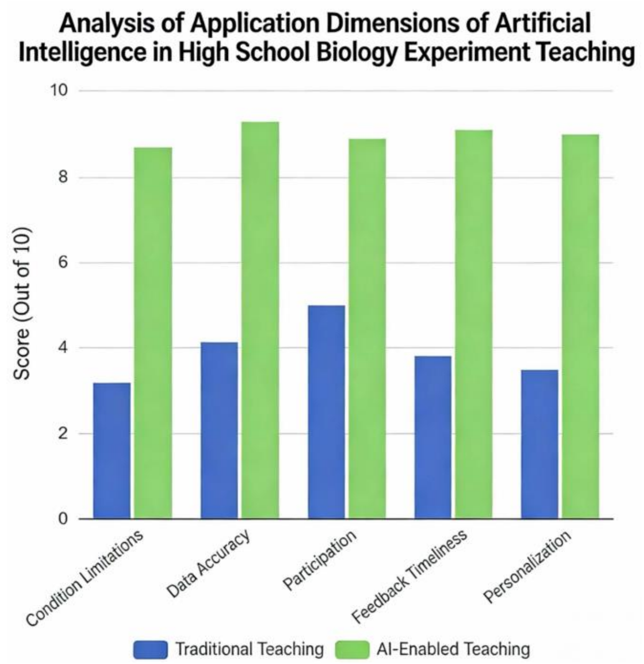

Figure 1. *Analysis of the Application Dimensions of AI in High School Biology Experiment Teaching.*

Attributed to this technological integration, teaching processes are optimized, and teacher-student interaction paradigms are redefined. Research indicates that AI-powered interactive platforms can facilitate real-time Q&A and error diagnosis through natural language processing, leading to a tripartite collaborative teaching loop of "student-machine-teacher" [1]. Nevertheless, technological integration also raises ethical risks such as algorithmic bias, data privacy breaches, and the diminishing role of teachers [4], which necessitate the establishment of corresponding regulatory frameworks and digital ethics guidelines in basic education [1]. In addition, high technical deployment costs and gaps in teachers' digital literacy present practical challenges to its widespread implementation in underdeveloped regions [1]. Consequently, a tripartite development approach that integrates "policy-technology-teacher" should be fostered to facilitate AI's deep transformation from instrumental assistance to paradigm innovation in education, ultimately aiming for high-quality scientific education empowered by technology [5].

1.2. Research Objectives and Framework

Within the framework of interdisciplinary integration under the "Artificial Intelligence (AI) + X" educational paradigm, high school biology experiment teaching is undergoing a critical transition from traditional models to intelligent and personalized approaches [6]. Although experimental teaching is still indispensable for cultivating students 'scientific inquiry skills and practical competencies, ongoing issues, including the impracticality of high-risk experiments, the absence of microscopic process visualization, inefficient data processing, and a lack of personalized guidance, seriously impede the effective implementation of key competencies [7]. Concurrently, empirical evidence from reforms in university-level basic courses indicates that reconstructing experimental teaching models using information technology, especially AI-driven solutions, can greatly improve students' practical skills and innovative awareness [8]. Consequently, fully integrating AI technology throughout high school biology experiment teaching has emerged as a pivotal pathway to modernize science education.

This study examines the current application status and optimization strategies of AI technology in high school biology experiment teaching, intending to construct an intelligent teaching framework that encompasses four dimensions: experimental preparation, operational implementation, data analysis, and extended learning [7]. By adopting virtual simulation systems for immersive pre-experiment preparation, employing computer vision and natural language processing technologies for real-time operational feedback, and leveraging machine learning algorithms for automated modeling and visual analysis of experimental data, this method not only addresses spatial-temporal and resource limitations but also improves teaching precision and interactivity [7]. For instance, in the experiment "Observation of DNA and RNA Distribution in Cells", the AI-driven image recognition module aids students in assessing staining effects and performing localization analysis, significantly enhancing the scientific validity and reproducibility of experimental results [7]. Moreover, the embedded AI experimental platform designed in line with the industry-education integration concept offers a transferable technical paradigm for secondary education. Its multi-layered hierarchical structure facilitates cross-scenario expansion and deep integration with project-based learning [6]. This framework not only meets the demand for cultivating Type I ³talents but also provides theoretical foundations and practical examples for the intelligent transformation of science education.

2. Theoretical Basis and Conceptual Definition

2.1. Theory of Artificial Intelligence Education Application

The formulation of AI education application theories lays the foundation for deep integration into disciplinary teaching. In the current landscape of educational digital transformation, AI technology is transitioning from auxiliary tools into a fundamental driver that reshapes teaching paradigms [6]. Its theoretical framework encompasses several dimensions, including constructivist learning theory, situational cognition theory, and intelligent agent theory, highlighting the importance of learners' active construction and dynamic interaction supported by technological tools. Particularly, within the realm of experimental teaching, AI enables real-time modeling and feedback regulation of students' cognitive states through data-driven learning analysis mechanisms, thus aiding personalized inquiry path design [4]. This process not only depends on algorithmic model optimization but also necessitates a systematic architecture consistent with educational objectives, as illustrated by the multi-tiered teaching system present in embedded AI experimental platforms that promote knowledge transfer and competency advancement through modular design [6]. Meanwhile, the integration of information technology with disciplinary experiments should not merely be a simple superposition; it should serve as a logical starting point for interdisciplinary integration, reshaping curriculum content structures. For example, the integrated process "observation-modeling-identification" effectively links computational thinking with scientific inquiry [9]. Within this framework, AI acts not only as a technological carrier but also as a cognitive link between theory and practice. Notably, investigations of "triple-intelligent" education models in specialized fields like forensic evidence examination reveal that intelligent upgrading teaching systems must concurrently tackle structural elements, including the transformation of teacher roles, the enhancement of teaching supervision mechanisms, and the establishment of ethical norms [10]. Furthermore, international studies indicate that AI-powered online experimental teaching can substantially improve instructional efficiency and learning adaptability through the collection of multi-source data and the application of intelligent algorithms, supported by the integration of big data analytics and machine learning in instructional decision-making [9].

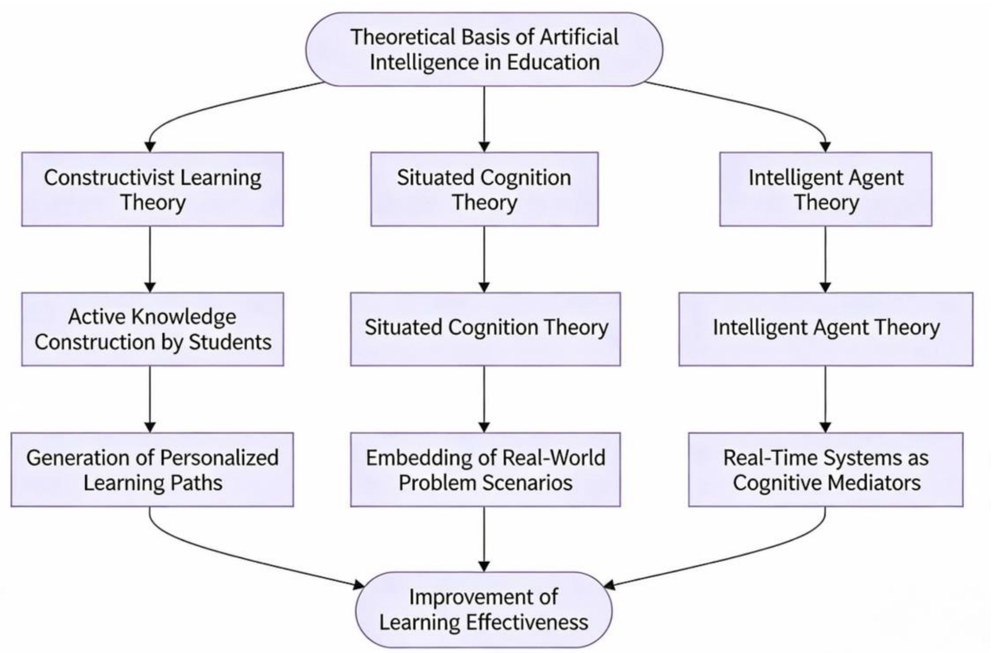

Figure 2. *Theoretical Basis of AI in Education.*

The above theoretical framework offers multi-dimensional support for the intelligent transformation of high school biology experiment teaching. It encompasses the explanation of the learning mechanism at the cognitive level and the logical system architecture at the technical implementation level, thereby establishing a solid theoretical foundation for future innovations in teaching modes.

2.2. The Connotation of Biology Experiment Teaching in Senior High School

High school biology experiment teaching is a vital component of science education as it not only involves knowledge verification and skill training but also aims to develop students' scientific inquiry abilities, critical thinking, and innovative capabilities [11]. In the context of new curriculum reform, experimental teaching has undertaken the critical mission of implementing essential competencies, highlighting the promotion of students' in-depth understanding of life phenomena and systematic mastery of scientific methods through both real and simulated scientific practice processes [5]. Nevertheless, traditional teaching models typically face challenges in experimental safety conditions, observability of microscopic processes, and efficiency of data processing, which limit the feasibility of conducting high-risk or highly abstract experiments [11]. For example, experiments involving staining and microscopic imaging, such as "observing the distribution of DNA and RNA in cells," are usually complicated by intricate operations and time-consuming procedures, which can disrupt teaching pace and affect learning outcomes. Meanwhile, significant differences in students' abilities render uniform guidance insufficient to meet personalized learning needs, further hindering the improvement of teaching quality.

To overcome these challenges, AI technology is increasingly being integrated into every facet of experimental teaching, showcasing its potential to revolutionize instructional workflows [11]. Virtual simulation platforms allow students to safely rehearse high-risk experiments, improving their cognitive preparedness. Smart sensors provide continuous monitoring of physiological parameters, significantly enhancing data accuracy and real-time monitoring capabilities [11]. Moreover, data analysis modules empowered by machine learning automatically identify experimental trends and generate visual charts, alleviating cognitive burdens for educators and students during post-processing [11]. Building on this, AI-driven interactive learning systems offer tailored guidance based on student behavior patterns, allowing for precise interventions. This technology-driven transformation of teaching paradigms not only enhances time efficiency and quality control in experimental procedures but also paves the way for an integrated smart teaching loop encompassing "preparation—implementation—analysis—extension" [11].

3. The Application of Artificial Intelligence in Teaching

3.1. Overview of AI Education Applications at Home and Abroad

In recent years, the rapid development of AI technology has led to its integration and application in basic education, particularly showcasing great potential in science experiment teaching. Numerous studies and practices, both domestically and internationally, suggest that AI-enhanced experimental teaching is transitioning from traditional models to intelligent and personalized approaches. In primary school science education, AI effectively improves students' inquiry abilities and cognitive quality through the implementation of constructing virtual experiment rehearsal systems, intelligent tool-assisted operations, and data visualization analysis. It also provides technical support for the design of teaching objectives and refinement of evaluation mechanisms [12]. Such teaching models not only transcend the spatiotemporal limitations of experimental teaching but also enrich students' comprehension of abstract scientific concepts [1]. Meanwhile, teaching practices based on the typical case of "image recognition technology in daily life" demonstrate that experimental teaching can function as an essential pathway for primary school students to engage with AI, providing unique advantages in fostering computational thinking and interdisciplinary literacy [13].

In a broader educational context, the deep integration of AI with web technologies and "Internet+" has propelled the systematic restructuring of experimental teaching platforms. For example, systems such as the all-in-one card management platform, intelligent monitoring framework, and online experiment booking platform—constructed using programming languages like JAVA, HTML, and Python—have enabled efficient allocation of teaching resources and real-time collection of process data [14]. These platforms not only improve laboratory management automation but also offer reliable data support for formative assessment. It is noteworthy that while most research emphasizes experimental teaching reforms in higher education or economic management (exemplified by the economic management experimental teaching demonstration center established at Inner Mongolia University), this model also provides valuable insights for organizing and conducting experimental courses in basic education stages [12].

However, the integration of AI into experimental teaching still encounters several challenges, such as high implementation costs, a lack of digital literacy among educators, and ethical issues concerning data privacy [13]. To address these issues, constructing a learner-centered smart ecosystem necessitates a tripartite mechanism involving policy guidance, teacher training, and technological advancement. The diagram below outlines the essential pathways for integrating AI into high school biology experiments and their multidimensional support framework:

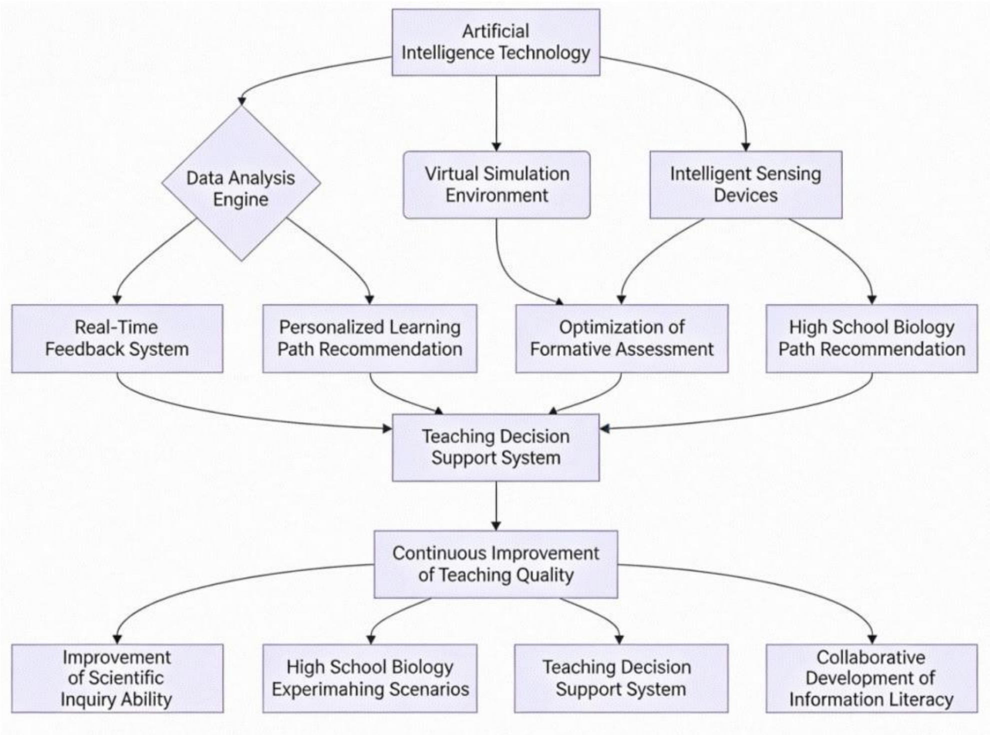

Figure 3. Essential Pathways for Integrating AI into High School Biology Experiments and Their Multidimensional Support Framework.

This model illustrates the transmission mechanism of AI technology, from foundational support to advanced instructional outputs, underscoring the key role of data-driven methodologies and human-machine collaboration in transforming experimental teaching. Future studies should further investigate the transferability of AI adaptive algorithms in biological micro-experiments, while constructing cross-regional intelligent teaching resource-sharing networks to improve educational equity and quality.

3.2. Practice of AI in Biology Experiment in Senior High School

In the current educational digital transformation, AI technology is increasingly influencing multiple aspects of high school biology experimental teaching, propelling traditional teaching models towards more intelligent and personalized approaches. This study utilized a mixed-methods research approach with a phased implementation: First, purposive sampling was performed to select five high schools within a teaching and research community in Zhengzhou as representative sites, thereby ensuring regional diversity in faculty quality, hardware infrastructure, and participation in curriculum reform. Then, stratified random sampling was applied to recruit 2,274 students from grades 10 and 11 (covering various academic proficiency levels with a distribution of high-achievers, average performers, and struggling learners approximately in a ratio of 1:2:1), and 82 current biology teachers were invited to participate. Data collection took place over a period of six weeks, during which structured questionnaires (Cronbach's $\alpha = 0.89$) and semi-structured interviews (each lasting from 45 to 60 minutes, fully transcribed from audio recordings) were conducted simultaneously. All qualitative data were independently coded using a three-level coding system (open–axial–selective) by the author, achieving a Kappa consistency coefficient of 0.86. For data analysis, a triangulation strategy was employed: quantitative data were analyzed with SPSS 26.0 for descriptive statistics and chi-square tests ($\alpha = 0.05$), while qualitative texts were processed with Nvivo 12 for theme extraction and contextual relevance analysis, systematically investigating the current application status of AI in experimental teaching. The results indicated that while awareness of AI technology has reached 87.3%, its routine classroom adoption rate is still limited to 35.4%, suggesting that technology promotion remains in its early stages. Regarding implementation forms, virtual simulation platforms are extensively used in microscopic experimental scenarios such as "observing DNA and RNA distribution in cells," effectively overcoming observation limitations posed by traditional equipment. AI modeling and visualization are widely used in research scenarios like "simulating genetic laws" to visualize abstract processes. Meanwhile, generative artificial intelligence (GenAI) is employed to design contextualized test questions and personalized learning pathways, allowing for interactive Q&A testing through natural language processing technology, thereby improving students' investigative motivation and cognitive depth [3]. Particularly, in genetics experiment modules, AI enhances immersive learning experiences by simulating Mendelian inheritance patterns using algorithms, thereby making abstract concepts tangible and improving students' comprehension of complex genetic mechanisms [7].

Table 1. *Survey data results.*

Application scenarios	Technology type	Operating frequency (%)	Enhanced student comprehension (Likert 5-point scale)	Improved experiment efficiency (minutes per class)	Security awareness score (5-point scale)
Microstructural observation	virtual simulation	11.0	4.2	18	4.6
genetic law simulation	AI Modeling and Visualization	35.4	4.5	15	4.7
Design and Implementation of the Experimental Scheme	AI Intelligent Guidance System	18.3	3.9	11	4.3
data analysis and processing	Experimental Data Analysis Tool	18.3	3.9	11	4.3

The utilization of the previously mentioned multimodal technologies has not only optimized experimental workflows but also positively influenced cognitive construction. Surveys show that more than 70% of students perceive AI-enhanced experiments as more participatory and exploratory, especially in the realm of data processing. AI-driven automated analysis tools can instantly produce regression curves and significance test outcomes, minimizing manual calculation errors and improving the rigor of scientific arguments [15]. Furthermore, AI interactive platforms facilitate asynchronous learning and real-time feedback, allowing for personalized guidance and addressing teaching blind spots that arise from imbalances in teacher-student ratios in traditional classrooms [7]. Nevertheless, potential risks behind technological applications necessitate vigilance. Relevant studies have indicated that generative AI may reflect cultural representation biases in image and content output. For example, the repeated depiction of stereotypical symbols like white coats and goggles during simulated science classes could unintentionally reinforce a singular cognitive framework of scientific identity [16]. Therefore, as AI is increasingly integrated into education, it is crucial to establish ethical review mechanisms to ensure that technological presentation remains diverse and inclusive.

To sum up, the integration of AI into high school biology experiment teaching has reached an initial scale, encompassing four key dimensions: preparation, operation, analysis, and extension. This has led to a novel teaching paradigm characterized by "virtual-real integration and human-machine collaboration" [15]. Future advancements should prioritize constructing interdisciplinary AI teaching models while ensuring data security and algorithm transparency, alongside improving teachers' digital literacy training. Such an approach aims to harmonize technological empowerment with the fundamental principles of education [17]. Only through such efforts can the profound potential of AI in science education be fully harnessed under the guidance of core competencies.

4. Analysis of Application Problems and Challenges

4.1. The Realistic Obstacle of Technology Integration

While AI technology exhibits transformative potential in high school biology experiment teaching, its integration with current educational systems encounters numerous practical challenges. The foremost challenge hindering the implementation of AI-powered experimental teaching is inadequate infrastructure. 80.5% of teachers report inadequate school policy support, as most institutions do not possess AI-compatible devices and high-speed network environments, making critical functions like virtual simulations and real-time data analysis impractical. Meanwhile, educators often lack operational experience with AI systems and teaching adaptation skills. Additionally, structural deficiencies in digital literacy impede the effective integration of AI tools into experimental design, process monitoring, and outcome evaluation [4]. Notably, this disconnect between technology and teaching is not isolated but intertwines with issues like outdated curriculum standards and uneven allocation of experimental resources, which together pose systemic reform barriers [8].

The complexity of employing AI in experimental teaching arises from the need for highly structured data inputs and standardized operational procedures, whereas high school biology experiments are characterized by strong openness and an exploratory nature. Projects such as observing cell mitosis or constructing ecological bottles involve a multitude of nonlinear variables and subjective judgments, posing significant challenges for training and deploying AI models [6]. Furthermore, intelligent upgrades to laboratory management systems necessitate cross-platform compatibility, including a combination of functional modules like experiment scheduling, equipment allocation, and safety monitoring. At present, most systems operate in isolation, lacking unified data interfaces and protocol standards [14]. In this context, building an AI-integrated teaching framework requires not only hardware investment but also the reconfiguration of knowledge organization logic and teacher-student interaction paradigms in experimental teaching [10].

These challenges illustrate that mere technological accumulation cannot lead to a quantum leap in educational efficacy. It is crucial to establish an ecological mechanism for the synergistic evolution of "technology-human-institution". For example, by adopting the "triple-intelligent" educational model, AI can be transformed from an auxiliary tool into a cognitive partner by redefining experimental teaching objectives, optimizing resource allocation pathways, and improving formative assessment feedback [10]. At the same time, modular design of experimental platforms under industry-education integration is essential for enhancing system scalability and contextual adaptability, thereby providing structural support for the sustainable advancement of intelligent education [6].

4.2. Inadequate Adaptability of Teaching Models

Though AI technology has begun to be implemented in high school biology experiment teaching, the adaptation of teaching models remains inadequate. Common challenges include fragmented application scenarios, superficial human-computer interaction, and shallow integration of teaching logic. Most AI-assisted systems remain operating at the "tool substitution" level and struggle to deeply integrate with the cognitive development pathways of experimental teaching [7]. For example, in microscopic experiments like "Observing DNA and RNA Distribution in Cells," although virtual simulation platforms can vividly illustrate staining processes, their feedback mechanisms usually adhere to preset paths, lacking real-time reasoning and adaptive guidance based on student operations. This constrains the potential for inquiry-based learning. Moreover, while AI-driven learning analytics can uncover learning barriers through data mining, their outputs often do not align with teachers' instructional decisions in practice, highlighting the contradiction between inadequate algorithmic interpretability and misalignment with educational contexts [4]. This misalignment between technological logic and teaching logic further intensifies the tendency towards "formalization" in AI applications.

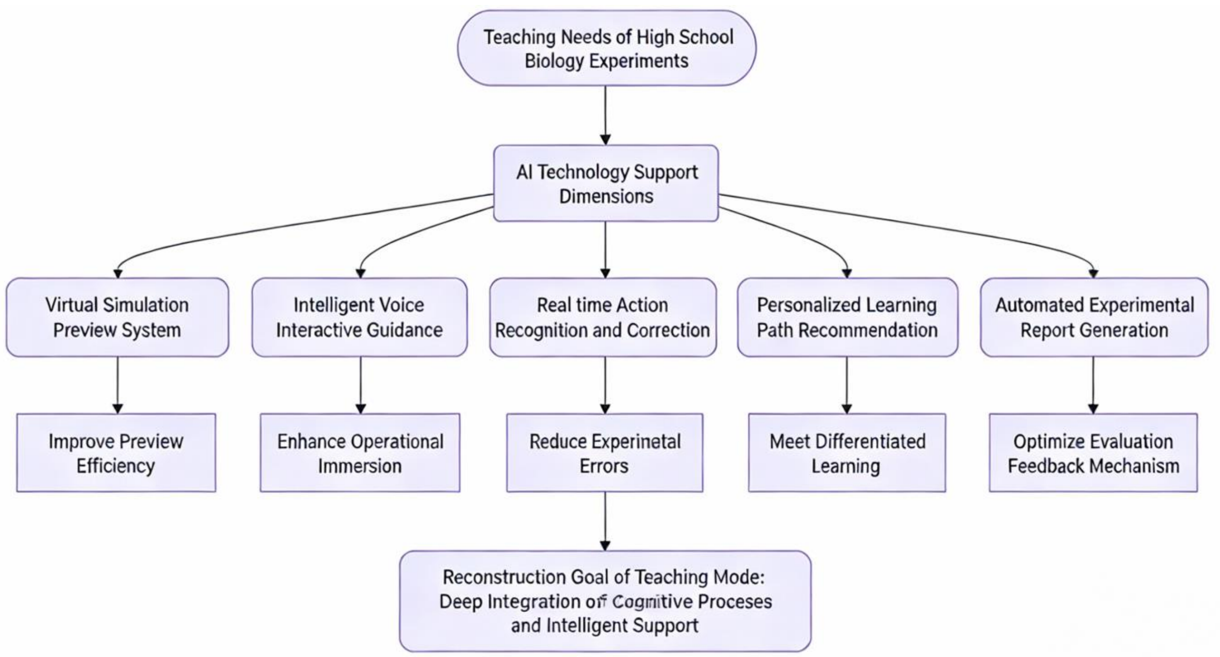

Figure 4. *Pathway Diagram of AI Technology Supporting the Needs of High School Biology Experiment Teaching.*

The underlying issue is that existing AI teaching systems frequently overlook the crucial characteristics of "embodied cognition" and "inquiry cycles" in science education, failing to accurately replicate the trial-and-error, reflection, and iterative processes in real experiments [7]. For example, in genetics experiments, students' grasp of Mendel's segregation ratios depends not just on data presentation but also on internalization through the cognitive closed-loop of hypothesis-testing and adjustment. Yet, most current AI modules only offer result-matching functions, lacking the ability to model students' thought processes. Meanwhile, GenAI exhibits cultural representation biases in image and text generation processes, such as stereotyping laboratory scenes with white coats and beakers, which can reinforce students' narrow perceptions of scientific identity and affect the establishment of their scientific identity [16]. Consequently, future designs for AI teaching models must move beyond technical superposition and shift toward creating a "collaborative intelligent" experimental ecosystem based on cognitive science, thereby facilitating a paradigm shift from "machine execution" to "teacher-student-AI co-creation."

5. Development Path and Strategy Construction

5.1. Innovation of Teaching Mode with Technology

In the realm of digital transformation in education, AI technology is increasingly infiltrating all domains of basic education, particularly showcasing significant application potential in high school biology experiment teaching. Traditional methods of experimental teaching face challenges due to equipment limitations, safety risks, and data collection accuracy, making it difficult to fully meet the new curriculum standard that emphasizes the coordinated development of scientific inquiry skills and core competencies [2]. To address these challenges, an AI-powered technological empowerment model has been developed. By creating intelligent, immersive, and personalized teaching environments, the model facilitates a shift from "experience-driven" to "data and algorithm dual-driven" experimental teaching [15]. In this context, virtual simulation pre-enactment systems can accurately replicate dynamic microscopic processes, such as visualizing the distribution of DNA and RNA within cells, allowing students to engage in high-risk or irreversible experiment pre-operation training in a risk-free environment [15]. Meanwhile, generative AI can automatically produce contextualized test questions and interactive Q&A content aligned with curriculum objectives, improving students' cognitive engagement and problem-solving skills [3].

The four-dimensional model indicates that AI offers the strongest support during the experimental preparation phase, achieving a noteworthy value of 92%, underscoring its pivotal role in knowledge pre-construction. Moreover, the combined use of intelligent sensors and real-time feedback systems during experimental operations substantially improves the spatiotemporal resolution and measurement reliability of data acquisition, mitigating the subjective errors inherent in traditional manual recording [2]. For example, in the "Investigating Factors Affecting Photosynthesis" experiment, the AI-driven light intensity and CO_2 concentration monitoring module provides millisecond-level dynamic response, while machine learning algorithms help predict nonlinear relationships between variables, aiding students in developing quantitative models [2]. Additionally, the AI data analysis module not only automates curve fitting and outlier identification but also produces personalized diagnostic reports based on students' operational paths, allowing for precise formative assessment [15]. In terms of cross-scenario expansion, leveraging the experience of integrating AI with virtual experiments in elementary science curricula, high school institutions could construct cross-stage, interdisciplinary intelligent inquiry platforms to promote knowledge transfer and deep learning [13]. It is noteworthy that, although AI technologies like image recognition have been tentatively used in elementary information technology experiments [13], deeper integration into high school biology necessitates technical interface standards and ethical review mechanisms to ensure teaching data security and algorithm transparency. Future studies should concentrate on developing multimodal learning analysis frameworks that incorporate eye-tracking, voice interaction, and behavioral log data sources to comprehensively characterize students' cognitive trajectories during AI-enhanced experiments.

5.2. Support System for Enhancing Teachers' Competence

The deep integration of AI technology in high school biology laboratory instruction has generated new requirements for teachers' professional development. As educational informatization advances rapidly, educators need to not only master traditional experimental teaching design and implementation skills but also develop competencies in operating intelligent educational tools, comprehending algorithmic logic, and facilitating human-machine collaborative teaching [8]. At present, high school biology teachers generally encounter obstacles such as insufficient AI literacy and inadequate technical application capabilities, hindering their ability to effectively employ intelligent systems for learning diagnostics, personalized feedback, and teaching optimization. Thus, constructing a systematic and sustainable support system for teacher competency enhancement has become a key step in fostering the deep integration of AI with experimental teaching.

From a practical perspective, the development of intelligent experimental teaching environments relies on educators' understanding and application of data-driven pedagogical principles. For example, AI-powered learning analytics models can accurately identify learning barriers and suggest targeted interventions by gathering multidimensional data, including students' operational trajectories, response durations, and error patterns in virtual experiments [4]. Nevertheless, educators who lack basic knowledge of machine learning principles and educational data interpretation methods may find it challenging to convert these technological outputs into effective instructional decisions. To address this issue, a tiered AI literacy training framework should be constructed, encompassing topics like operating smart education platforms, interpreting educational data, and human-machine collaboration strategies. This framework should be enriched with case studies and action learning to enhance practical application capabilities.

Additionally, the technical infrastructure of experimental teaching platforms must offer robust support for educators. By leveraging the experience of embedded AI experimental teaching reforms, intelligent teaching support systems characterized by high openness and strong interface compatibility can be developed, enabling teachers to conveniently use AI modules in real teaching scenarios, such as automatic grading, virtual teaching assistants, and visualization tools for experimental process [6]. Such platforms not only lower technical barriers but also provide practical platforms for teachers to pursue teaching innovation. Inspired by the "Three-Element" intelligent education model used in trace inspection laboratory programs, high school biology experimental teaching could investigate collaborative teacher training pathways involving universities, secondary schools, and enterprises, thereby enhancing cross-disciplinary cooperation and resource integration [10].

It is essential to emphasize that although technology empowers educational practices, ethical standards and the autonomy of teaching professionals should be safeguarded. As the primary force in instructional design, teachers should retain their leading role with the support of intelligent systems, avoiding the risk of "technological dependency" [4]. Consequently, the support framework should incorporate ethical training in smart education, assisting teachers in addressing issues like data privacy and algorithmic bias with prudence. In summary, only using a tripartite long-term mechanism that integrates institutionalized training, technical support, and ethical guidance can we comprehensively improve high school biology teachers' competencies in intelligent teaching, thereby unlocking the true value of AI in experimental education [9].

6. Conclusion and Prospects

6.1. Summary of Main Findings

Current high school biology experiment teaching encounters several challenges when conducted under traditional models, including limited experimental conditions, invisibility of microscopic processes, low data collection accuracy, and inadequate personalized guidance, which significantly hinder the in-depth development of students' scientific inquiry abilities and core competencies [2]. In this regard, the integration of AI technology opens new avenues for the systematic reconstruction of experimental teaching. Generative AI, with its capabilities in natural language processing and content generation, has shown considerable potential in contextualized test design, intelligent Q&A interaction, and experimental protocol optimization, effectively improving the interactivity and exploratory nature of learning [3]. Meanwhile, virtual simulation technology allows for the safe and visual implementation of high-risk or microscopically difficult-to-observe experiments, such as "observing the distribution of DNA and RNA in cells" by constructing highly realistic experimental environments, overcoming the limitations imposed by physical space and experimental materials [15]. The integrated application of smart sensors and IoT devices enables real-time collection and dynamic feedback of multimodal data (e.g., temperature, light, gas concentration) during experiments, considerably enhancing measurement accuracy and reproducibility [2]. More importantly, data analysis modules developed based on machine learning algorithms can automatically detect student operational deviations and offer personalized real-time guidance suggestions, thereby shifting the paradigm from "standardized teaching" to "adaptive learning" [15]. In addition, AI-powered interdisciplinary integration platforms have fostered deep integration between biology and information science/engineering, providing essential technical support for project-based learning and inquiry-based experimental design, thus propelling science education towards cross-disciplinary collaborative development [4]. Nonetheless, despite these technological advancements, challenges persist, including a misalignment between pedagogical and technical logics, insufficient digital literacy among teachers, and concerns regarding data privacy and ethical standards [4]. Future strategies should emphasize establishing a tripartite collaborative teaching framework of "AI-teacher-student", improving teachers' instructional design capabilities and human-machine collaboration in intelligent environments [4]. Meanwhile, comprehensive policy guidance and ethical review mechanisms should be instituted to guarantee educational appropriateness and safety in technology application [4]. In conclusion, the deep integration of AI in high school biology experimental teaching arises not only from technological iteration but also from an inevitable transformation and upgrading of science education concepts. Its sustainable development depends on the synergistic resonance of technological, institutional, and humanistic values [5].

6.2. Future Research Directions

As artificial intelligence technology increasingly integrates into the education field, high school biology experimental teaching stands at a pivotal juncture of paradigm transformation. Future investigations should prioritize constructing mechanisms for deep integration of AI and science education, particularly by identifying methods to optimize cognitive load and promote collaborative development of deep learning across disciplines [1]. Current studies have indicated that utilizing intelligent recognition systems and data modeling tools has markedly enhanced students 'understanding of Mendel's laws of segregation and linkage exchange in genetics experiments, highlighting the unique advantage of AI-enabled instructional design in concretizing abstract concepts [7]. Nevertheless, the deployment of such technologies remains fragmented, with a lack of systematic frameworks for curriculum reconstruction. There is an urgent need to implement the closed-loop design concept of "task-driven—model construction—intelligent feedback" from using information technology experimental teaching to shift biological experiments from verification-based operations to exploratory practices [18]. Meanwhile, the broad implementation of GenAI provides new possibilities for automated generation of teaching resources, yet the stereotypes and cultural biases present in its outputs cannot be ignored. For example, the image of science teachers is typically stereotyped with specific attire and gender characteristics, reflecting structural biases in algorithmic training data [16]. As a result, future empirical studies should not only aim to improve academic performance supported by AI technology but also incorporate critical perspectives, utilizing mixed methods to explore the influence of technological intervention on teacher-student interaction patterns, classroom discourse distribution, and scientific identity recognition. In addition, considering that the systematic teaching model for experimental education in economics and management has been validated by long-term practice [12], the high school biology curriculum could benefit from adopting its tiered experimental design approach. This would construct a three-tiered AI-integrated experimental framework that involves foundational skill development, comprehensive problem-solving, and open innovation projects. Large-scale longitudinal studies should be carried out to assess the framework's sustainability and scalability, providing theoretical foundations and practical models that ensure equity, effectiveness, and ethical standards in science education during the era of intelligence.

Abbreviations

GenAI	Generative Artificial Intelligence

Author Contributions

Mingwei Zhang is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

Appendix I: Teacher Comprehensive Assessment Questionnaire

"Teacher Comprehensive Assessment Questionnaire"

Dear teacher:

Dear Sir/Madam, this questionnaire is designed to assess the integration of artificial intelligence technology in high school biology experiment teaching. The questionnaire will be completed anonymously, and all information collected will be used exclusively for academic research purposes. We appreciate your participation.

1. Basic Information

1. Your teaching experience:

□ 1-3 years

□ 4–10 years

□ 11–20 years

□ Over 20 years

2. Teaching grade (multiple selections allowed):

□ Senior One

□ Senior Two

□ Senior

II. Overview of AI Usage

4. How often do you use AI technology in your biology lab classes?

□ <10% of class hours

□ 10%—30%

□ 30%—50%

□ >50%

5. AI tools you use (multiple selections allowed):

□ Virtual Simulation Experiment Platform

□ AI Intelligent Guidance System
□ Experimental data analysis tool
□ AI Modeling and Visualization
□ Others: ___________________
III. Comparative Evaluation of Experimental Outcomes
6. Comparison of experiment duration:
Traditional experiments typically require an average of ______ minutes.
After AI assistance, the average time required is ______ minutes.
7. Improvement in student experiment accuracy rate:
□ <5%
□ 5%—15%
□ 15%—30%
□ >30%
8. Improved efficiency per lab session (time saved):
<10 minutes
□ 10-20 minutes
□ 20-30 minutes
More than 30 minutes
IV. Multi-dimensional scoring (1-5 points, please circle)
9. Increased student engagement:
1□ 2□ 3□ 4□ 5□
10. Improved student comprehension:
1□ 2□ 3□ 4□ 5□
11. Enhanced safety awareness in experiments:
1□ 2□ 3□ 4□ 5□
12. Teacher guidance efficiency improvement ratio:
1□ 2□ 3□ 4□ 5□
(1=No improvement, 5=Great improvement)
V. Challenges and Barriers in AI Applications (Multiple Selection Allowed)
13. What do you think are the main obstacles?
□ Insufficient device or network conditions
□ Teachers lack relevant training
□ Does not match the existing course content
□ Students are not adapting to the new way
□ Teaching effectiveness is unclear
□ Insufficient support from school policies
□ Others: ___________________
VI. Open-ended Questions
14. Please provide a brief description of a specific case where an AI technology was successful (or failed) in biological experiment teaching:

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____

____

Appendix II: Student Comparison Experience Questionnaire

Student Comparison Experience Questionnaire
Hello, classmate:
Please fill out this form based on your experience in biology lab courses, comparing the two scenarios with and without AI assistance.
1. Basic Information
1. Grade:
□ Senior One
□ Senior Two
□ Senior

2. Have you used AI-assisted biological experiments (such as virtual simulation or intelligent guidance)?
□ Yes (Please continue to fill in the form below)
□ No (only fill in the "No AI assistance" column)
2. Experience Comparison Rating (1-5 points)

Table 2. *Experience Comparison Rating (1-5 points).*

problem description	**AI-assisted (1-5 points)**	**No AI assistance (1-5 points)**
3. I can focus better in lab classes	1□ 2□ 3□ 4□ 5□	1□ 2□ 3□ 4□ 5□
4. I can better understand the experimental principles and procedures	1□ 2□ 3□ 4□ 5□	1□ 2□ 3□ 4□ 5□
5. The experimental operation process is smoother and time-saving	1□ 2□ 3□ 4□ 5□	1□ 2□ 3□ 4□ 5□
6. I feel safer in the experimental environment	1□ 2□ 3□ 4□ 5□	1□ 2□ 3□ 4□ 5□
7. I am more interested in biological experiments	1□ 2□ 3□ 4□ 5□	1□ 2□ 3□ 4□ 5□

III. Open Feedback
8. How do you think AI technology can be further enhanced in biology lab classes?

The survey is complete. Thank you for participating.

References

[1] Xu Guofeng. The Impact of Artificial Intelligence Technology on Interdisciplinary Experimental Teaching [J]. Primary Science: Teachers, 2025, (5): 88-90.

[2] Wang Xin-Xian. Design of AI-empowered High School Biology Experiment Teaching [J]. Today's Digest, 2025, (20): 76-78.

[3] Zhou Y. Application and Innovation of Generative AI in High School Biology Experiment Teaching [J]. Middle School Biology Teaching, 2025, (27): 54-56.

[4] Wu Haozhen, Cui Min, Yuan Yibiao. The Construction and Challenges of Artificial Intelligence in the Application of Functional Medicine Experimental Teaching [J]. Basic Medical Education, 2025, 27(1): 86-90.

[5] Wang Yubin. Grounding in the Reform of High School Biology Experiment Teaching to Cultivate Students' Scientific Literacy [J]. Secondary School Curriculum Guidance (Teaching Research), 2019, 013(006): 66-67.

[6] Lu Lingxia, Yu Miao, Peng Yonggang. Explorations in Embedded Artificial Intelligence Experimental Teaching for I^3 Type Excellence Talent Cultivation [J]. Laboratory Research and Exploration, 2025, 44(1): 85-90.

[7] Zhang Qiaoxian, Zhai Yuhao, Bai Jian, Gao Xiaole. Exploration of the Application of Artificial Intelligence Technology in Genetic Experiment Teaching [J]. Foreign Animal Husbandry: Pigs and Poultry, 2025, 45(1): 98-103.

[8] Chao Chen. Research on Experimental Teaching Model Innovation from the Constructionist Perspective [C]. Mechanical engineering and technology. 2011.

[9] Meijuan Chen, Kaiwei Wang, Yufeng Wang, Xiaorong Zhu, Jianhua Shen. Teaching Exploration on the Deep Integration of Artificial Intelligence and Information Technology with Online Experiments [C]. IEEE International Conference on Teaching, Assessment, and Learning for Engineering. 2020.

[10] Zhou Hao. Explorations on Experimental Teaching Reform of Trace Examination in the Era of Artificial Intelligence [J]. Journal of Liaoning Police College, 2025, 27(1): 122-128.

[11] Cui Hongyu. Exploring the Pathways to Enhance the Effectiveness of High School Biology Experiment Teaching Through Problem-Based Learning [J]. Wen Yuan (Primary School Edition), 2020, 000(006): 684.

[12] MA Zhan Ying, BAO Si Qing Aowa. The Experimental Teaching System Design and Model Innovation of Economic Management in Colleges [C]. The Third International Conference on Education Management Science and Engineering (3rd International Academic Symposium on Education Management Science and Engineering). 2010.

[13] LAN Xuwen. Practical Exploration of Artificial Intelligence Experimental Teaching in Primary Schools: Taking "Image Recognition Technology Around Us" as an Example [J]. Experimental Teaching and Instruments, 2025, 42(1): 141-143. https://doi.org/10.19935/ki.1004-2326.2025.01.048

[14] Shuangyuan Li. Construction and Research of Internet+ Experimental Teaching Platform Based on Artificial Intelligence [C]. International Conference on Education, Management Science and Economics. 2019.

[15] Dai, N. Innovation and Practice of Experimental Teaching Strategies in High School Biology with AI Empowerment [J]. Research on Integrated Subject Education, 2025, (1): 52-55.

[16] Grant Cooper, Kok-Sing Tang. Pixels and Pedagogy: Examining Science Education Imagery by Generative Artificial Intelligence [J]. Journal of Science Education and Technology, 2024, 33(4): 556-568. https://doi.org/10.1007/s10956-024-10218-9

[17] Jun Li, Xiaolong Mei, Jinyang Wang, Beijing Xie, Yubin Xu. Simulation Experiment Teaching for Airport Fire Escape based on Virtual Reality and Artificial Intelligence Technology [C]. IEEE International Conference on Civil Aviation Safety and Information Technology. 2020. https://doi.org/10.1109/ICCASIT50869.2020.9368726

[18] Chen Kai. Gazing at the Stars, Illuminating Star Wisdom: An Example of Artificial Intelligence Experimental Teaching with Interdisciplinary Integration [J]. China Information Technology Education, 2025, (1): 17-21.