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FROM CURRICULUM TO TEXTBOOK: PATHWAYS FOR DEVELOPING "GOLD COURSES" AND "GOLD TEXTBOOKS" IN VOCATIONAL SPORTS TRAINING EDUCATION

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Abstract: In the context of China's ongoing vocational education reform, the construction of "gold courses" and "gold textbooks" has become a critical pathway for improving the quality of vocational sports training education. This paper explores the transformation from curriculum design to textbook development within the framework of competency-based education. Through an analysis of curriculum objectives, teaching content, instructional design, and resource integration, the study proposes a systematic approach to building high-quality teaching resources. The research emphasizes aligning course development with industry standards, enhancing the integration of theory and practice, and promoting the digitalization and innovation of teaching materials. By examining practical cases in sports training programs, this paper summarizes effective strategies for developing exemplary courses and textbooks that meet the needs of modern vocational education. The findings provide theoretical guidance and practical reference for educators and curriculum developers in vocational sports institutions.
Keywords: Vocational education; Sports training; Gold courses; Gold textbooks; Curriculum development; Teaching reform

1 INTRODUCTION

With the continuous advancement of China's vocational education reform, the concept of constructing "gold courses" and "gold textbooks" has emerged as a strategic measure to enhance teaching quality and promote high-level talent cultivation. In vocational sports training education, where practice, skills, and innovation intersect, developing these "gold standards" of teaching resources is essential to ensure that students acquire both theoretical knowledge and practical competence.

The Ministry of Education has repeatedly emphasized the importance of building high-quality curriculum systems that integrate moral education, professional skills, and lifelong learning capabilities. In this context, the "gold course" refers not only to courses with excellent design, advanced teaching methods, and rich digital resources, but also to those that effectively cultivate students' comprehensive abilities and align with industrial needs. Meanwhile, the "gold textbook" serves as a crucial carrier for course implementation, reflecting the integration of curriculum standards, teaching practice, and educational innovation.

However, many vocational institutions still face challenges such as outdated teaching content, weak curriculum–industry alignment, and insufficient textbook innovation. Particularly in sports training programs, where practical operation and situational teaching are indispensable, the development of courses and textbooks often lacks systematic planning and theoretical support.

Therefore, this study aims to explore the pathway from curriculum design to textbook development in vocational sports training education. It seeks to clarify the internal logic, key elements, and implementation strategies for constructing "gold courses" and "gold textbooks." By examining successful practices and theoretical models, this paper provides references for improving curriculum quality and fostering innovation in vocational sports education.

2 LITERATURE REVIEW AND THEORETICAL BASIS

2.1 Research on Curriculum Development in Vocational Education

Curriculum development in vocational education has long been recognized as the cornerstone of cultivating skilled and application-oriented talents. Early research, influenced by Tyler's classic curriculum theory[1], emphasized objectives, content, organization, and evaluation as four interrelated elements. In recent decades, with the rise of competency-based education (CBE), scholars have shifted attention from knowledge transmission to the development of professional competencies and workplace adaptability.

Internationally, many studies[2] highlight that vocational curricula must align closely with industry needs and labor market demands. Countries such as Germany and Australia have developed dual-system or modular curricula that integrate school learning with practical training. In China, the National Vocational Education Reform Implementation Plan proposed building "high-quality curricula" that reflect the spirit of craftsmanship and innovation[3]. Research in this context focuses on competency frameworks, modular design, and digital learning resources to improve the relevance and flexibility of vocational curricula[4,5].

In sports training programs, however, curriculum research remains limited. Most existing studies emphasize skill-based teaching, competition organization, and physical training methods, while the systematic design of vocational sports

curricula—particularly the linkage between curriculum objectives, teaching content, and assessment—requires further exploration.

2.2 Research on Textbook Construction and Quality Standards

Textbooks serve as both a teaching medium and a reflection of curriculum reform. Internationally, scholars[6,7] such as Tomlinson and Hutchinson & Torres have explored how textbooks embody pedagogical philosophy, curriculum standards, and learner-centered design. High-quality textbooks are characterized by clear structure, contextualized learning materials, and integration of multimedia and digital tools.

In China's vocational education field, the concept of "gold textbooks" has gained prominence since 2018, following the Ministry of Education's "Double High Plan" and the "Three-Education Reform" initiative (curriculum, teaching materials, and teaching methods). Studies define gold textbooks as those with innovative content, strong industry relevance, and a capacity to cultivate comprehensive vocational competence[8-9].

Yet, several challenges persist: textbook compilation often lags behind curriculum reform; content lacks integration with industrial technologies; and digital transformation remains uneven. Particularly in sports training education, textbooks tend to focus on traditional theories of physical education or sport science, with insufficient emphasis on applied vocational scenarios such as coaching practice, sports management, and emerging digital training technologies.

2.3 Theoretical Framework for the Study

To guide the exploration of pathways from curriculum to textbook development in vocational sports training education, this study is grounded in three complementary theoretical foundations, as summarized in Table 1.

Table 1 Theoretical Framework of the Study

Theory	Core Concepts	Application to This Study
Competency-Based Education (CBE)	Focuses on measurable learning outcomes that reflect job-related skills and performance; emphasizes alignment of curriculum objectives, teaching content, and assessment with industry standards.	Provides a foundation for designing "gold courses" that cultivate practical competencies required in sports training professions
Constructivist Learning Theory	Views learning as an active process where learners construct knowledge through experience, reflection, and interaction; stresses learner-centered and contextualized teaching.	Supports the development of interactive and experiential teaching activities, promoting deeper learning in sports training courses
Curriculum–Textbook Integration Theory	Highlights the dynamic relationship between curriculum standards and teaching materials; textbooks operationalize curriculum goals through structured and engaging content	Guides the translation of curriculum objectives into coherent, innovative, and practice-oriented "gold textbooks

To clarify the logical flow of this research, a technical route was developed to illustrate the progression from theoretical foundation to practical implementation. The route integrates key stages including curriculum design, textbook development, teaching practice, and continuous feedback, forming a coherent system for constructing "gold courses" and "gold textbooks" in vocational sports training education. The overall research framework is presented in Figure 1, which demonstrates the dynamic linkage between policy background, theoretical underpinnings, curriculum–textbook integration, and quality improvement mechanisms.
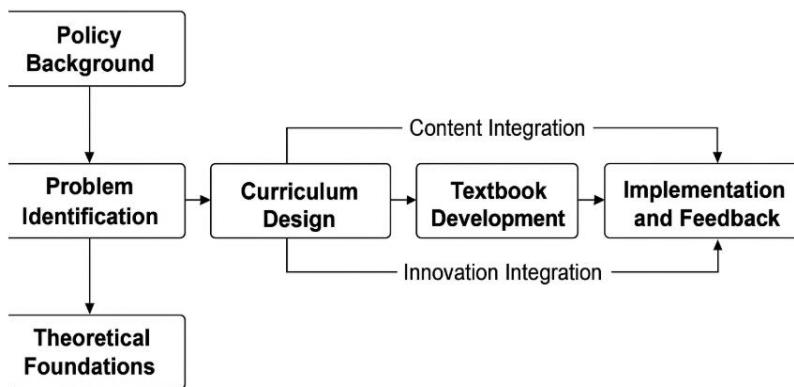
Figure 1 Technical Route of the Study

3 PATHWAYS FROM CURRICULUM TO TEXTBOOK IN VOCATIONAL SPORTS TRAINING

The pathway from curriculum design to textbook development in vocational sports training represents a dynamic and iterative process that links educational goals with pedagogical implementation. In vocational contexts, where learning outcomes are directly connected to industry needs, textbooks must not only convey theoretical knowledge but also provide concrete guidance for skill acquisition, performance assessment, and professional growth. Therefore, the

development of "gold courses" and "gold textbooks" must be based on a deep understanding of curriculum objectives, the logical alignment between standards and content, and the integration of teaching practice with innovation.

3.1 Curriculum Objectives and Industry Alignment

The foundation of curriculum development in vocational sports training lies in establishing clear, outcome-oriented objectives that reflect industry standards and professional competencies. Unlike general education, vocational curricula emphasize "learning by doing" and the cultivation of occupational abilities that meet labor market demands.
In recent years, China's vocational education reform has stressed the need for tighter connections between curricula and industry. Sports-related industries—such as fitness coaching, sports rehabilitation, event management, and youth training—require professionals who can combine technical expertise with pedagogical and organizational skills. Hence, curriculum objectives must integrate three key dimensions: knowledge competence, technical competence, and professional competence. Core dimensions of curriculum objectives in vocational sports training can be seen in table 2.

Table 2 Core Dimensions of Curriculum Objectives in Vocational Sports Training

Dimension	Definition	Key Learning Outcomes
Knowledge Competence	Theoretical understanding of sports science, physiology, and pedagogy.	Learners grasp core concepts of sports theory, anatomy, and instructional principles to support evidence-based training.
Technical Competence	Mastery of practical training methods and analytical tools	Students can design and implement training programs, apply coaching techniques, and conduct performance evaluations
Professional Competence	Application of ethics, teamwork, and innovation in professional contexts	Learners demonstrate responsibility, communication, leadership, and adaptability in sports-related workplaces

Curriculum objectives, therefore, should be collaboratively defined by educators, industry experts, and professional associations to ensure alignment with national occupational standards and the evolving needs of the sports sector. When these objectives are well articulated, they provide the foundation for selecting and structuring textbook content that truly supports competency development.

3.2 Logical Relationship between Curriculum Standards and Textbook Design

Curriculum standards serve as the blueprint for textbook development, specifying learning outcomes, content scope, teaching hours, and evaluation criteria. However, transforming abstract standards into concrete teaching materials is not a linear process—it requires pedagogical interpretation and creative adaptation. Textbook design thus functions as the operationalization of curriculum standards, translating educational goals into structured, engaging, and applicable learning experiences.
The logical relationships between curriculum standards and textbook design can be summarized in Table 3.

Table 3 Logical Relationship between Curriculum Standards and Textbook Design

Relationship	Curriculum Standards	Textbook Design Response	Expected Outcome
From Goals to Content	Define what students shouldachieve in terms of knowledge,skills, and attitudes	Translate learning outcomes into modularteachable units and thematic chapters.	Clear alignment betweencurriculum goals and teachingmaterials.
From Content to Pedagogy	Specify key concepts, topics,and required competencies	Organize content using pedagogical strategiessuch as task-based learning, case studies, andproject-based instruction.	Enhanced learner engagement andcontextualized understanding.
From standards to Evaluation	Set assessment criteria andcompetency benchmarks	Incorporate formative and summativeassessments, exercises, and practical evaluationtasks.	Ensure measurable learningoutcomes and feedbackconsistency.

In the field of sports training, this logical connection ensures that students can apply theoretical principles in real or simulated environments, bridging the gap between curriculum intention and instructional practice. The "gold textbook" thus acts as both a curricular bridge and a pedagogical engine, transforming standards into actionable learning experiences that foster competence and innovation.

3.3 Integration of Teaching Content, Practice, and Innovation

A hallmark of vocational education—especially in sports training—is the integration of theory and practice. Courses and textbooks that separate these dimensions risk producing graduates with limited practical competence. Therefore, innovation in curriculum and textbook design must emphasize authentic, practice-based learning that mirrors real professional contexts.

The integration of content, practice, and innovation in vocational sports training can be conceptualized as shown in Table 4.

Table 4 Integration of Teaching Content, Practice, and Innovation in Vocational Sports Training

Integration Dimension	Core Elements	Implementation Strategies	Expected Educational Outcomes
Content Integration	Theoretical knowledge ofsports science, pedagogy,and training principles	Design modular, scenario-based learningunits linked to actual coaching or trainingcontexts	Learners build solid theoreticalfoundations contextualized inreal-world situations
Practice Integration	Practical training, simulation and field experience	Combine classroom learning withinternships, workshops, and on-site training,use case-based and project-based teaching	Students develop applied skillsand professional confidencethrough experiential learning
Innovation Integration	Application of digital toolsresearch, and creativeproblem-solving	Incorporate multimedia resources (videosVR/AR, data analytics); encourageinnovation projects and reflective learning	Learners enhance creativity.technological literacy, andcapacity for continuousimprovement

Through these forms of integration, "gold courses" and "gold textbooks" become comprehensive platforms that blend knowledge, practice, and innovation. They promote the transition from teacher-centered instruction to learner-centered, competence-oriented education, fostering adaptable and innovative professionals for the modern sports industry.

4 STRATEGIES FOR DEVELOPING "GOLD COURSES" AND "GOLD TEXTBOOKS"

Building on the theoretical and structural pathways discussed earlier, this section proposes practical strategies for developing high-quality ("gold") courses and textbooks in vocational sports training education. The focus is on translating curriculum objectives into effective teaching practices, promoting the synergy of content, pedagogy, and innovation, and exemplifying successful implementation through case analysis.

4.1 Principles of "Gold Course" Construction

The construction of a "gold course" in vocational sports training must go beyond excellent content—it requires systematic design that integrates educational objectives, teaching methods, assessment, and innovation. A "gold course" should cultivate both technical competence and professional quality through engaging, practice-oriented learning.
To operationalize these ideas, Table 5 summarizes the core principles, implementation strategies, and expected outcomes of "gold course" construction.

Table 5 Principles and Implementation Strategies for "Gold Course" Construction

Principle	Description	Implementation Strategies	Expected Outcomes
Outcome Orientation	Focus on measurable competencies aligned with industry standards	Define clear learning outcomes based on national occupational standards and professional roles	Learners achieve tangible, verifiable competencies for sports-related professions
Integration of Theory and Practice	Blend academic knowledge with real-world applications	Employ task-based learning, on-field teaching, and dual-teacher models combining educators and industry coaches	Students develop applied problem-solving and operational skills
Digital and Interactive Learning	Use modern technology to enhance engagement	Introduce online platforms, data-based sports analysis, and multimedia resources	Improved learning motivation and digital literacy
Continuous Improvement	Ensure dynamic course evaluation and feedback loops	Establish monitoring mechanisms and iterative updates through student and industry feedback	Courses remain relevant, adaptive, and innovative

4.2 Standards and Characteristics of "Gold Textbooks"

While "gold courses" focus on teaching design, "gold textbooks" act as the primary vehicles for delivering curriculum standards in practice. They embody content selection, pedagogical design, and technological integration, forming a comprehensive learning system.
To establish a unified standard for such textbooks, Table 6 presents the core dimensions, key characteristics, and implementation approaches for "gold textbook" development in vocational sports education.

Table 6 Standards and Key Characteristics of "Gold Textbooks" in Vocational Sports Education

Standard Dimension	Key Characteristics	Practical Approaches	Intended Impact

Curriculum Alignment	Consistency with national standards, course objectives, and skill requirements	Develop content directly linked to learning outcomes and industry tasks	Ensures coherence between teaching, learning, and assessment
Content Relevance	Strong connection with professional practices and current industry trends	Integrate updated case studies, competition examples, and technological innovations	Increases applicability and authenticity of learning materials
Pedagogical innovation	Learner-centered and activity-based design	Include problem-solving tasks, reflective exercises, and collaborative projects	Encourages active learning and critical thinking
Digital and VisualDesign	Use multimedia and interactive formats for engagement	Combine print and digital materials	Enhances flexibility and accessibility
Sustainability and	Continuous renewal and adaptability to emerging technologies	Establish editorial committees with educators and practitioners for periodic review	Keeps textbooks relevant to evolving vocational contexts

4.3 Case Study: Practice in Vocational Sports Training Programs

To illustrate how the above strategies are applied in practice, a representative case is analyzed from Tianjin Vocational College of Sports, which has implemented a reform integrating "gold course" construction with "gold textbook" development in its Sports Coaching and Training program[10].
The key components and outcomes of this initiative are summarized in Table 7.

Table 7 Case Study: Construction Practice of a "Gold Course" and "Gold Textbook" in Sports Coaching

Aspect	Implementation Practice	Achievements
Curriculum Reform Focus	Reconstructed the "Sports Training Fundamentals" course based on competency-oriented modules	Improved coherence between theory, practical sessions, and internship experiences
Textbook Development	Developed a modular digital textbook integrating QR codes, video tutorials, and data-analysis examples	Increased learning interactivity and self-directed study engagement
Teaching Innovation	Introduced dual-teacher instruction (academic + industry expert) and blended online–offline delivery	Enhanced authenticity and flexibility of learning experiences
Evaluation and Feedback	Implemented multi-dimensional assessment (peer evaluation, self-reflection, practical tests)	Boosted student confidence, teamwork, and employability outcomes
Industry Collaboration	Partnered with local sports clubs and fitness organizations for training practice	Strengthened the link between classroom learning and real-world applications

5 DISCUSSION AND CONCLUSION

5.1 Discussion

The development of "gold courses" and "gold textbooks" in vocational sports training education reflects a fundamental shift from knowledge transmission to competence-oriented learning. The results of this study demonstrate that the success of such reform depends on the effective integration of curriculum objectives, teaching design, and industry participation.
First, curriculum objectives aligned with industry standards form the foundation of quality vocational education. Clear, outcome-oriented goals enable curriculum planners to design learning experiences that correspond to real occupational tasks. This alignment ensures that students develop both theoretical understanding and applied skills relevant to professional practice.
Second, the logical transformation from curriculum standards to textbook design is essential for translating abstract objectives into teachable content. As the study shows, textbooks should not merely serve as repositories of information but as instruments for applying knowledge, fostering reflection, and guiding practice. When textbooks embody curriculum standards through structured modules, contextual cases, and formative assessments, they become powerful tools for achieving learning outcomes.
Third, the integration of teaching content, practice, and innovation serves as the engine of high-quality course construction. Practical training, digital learning technologies, and scenario-based tasks help bridge the gap between classroom and workplace. Particularly in sports training, where experiential learning is crucial, the combination of virtual simulation, field practice, and reflective evaluation promotes deeper learning and professional adaptability.
Finally, the case of Tianjin Vocational College of Sports exemplifies how collaborative reform between educators and industry experts can create sustainable mechanisms for curriculum and textbook co-development. The success of this

model highlights that "gold courses" and "gold textbooks" emerge not from isolated innovations but from systematic collaboration, ongoing feedback, and institutional support.

5.2 Discussion

This study examined the pathway from curriculum development to textbook construction in vocational sports training education, emphasizing the creation of "gold courses" and "gold textbooks" as a key strategy for improving teaching quality and professional relevance. The research demonstrates that the essence of this transformation lies in the organic integration of curriculum objectives, textbook content, pedagogical practice, and industry collaboration.

The findings indicate that curriculum design rooted in industry-oriented, competency-based principles provides a solid foundation for course and textbook development. When curriculum standards are closely aligned with occupational requirements, textbooks can effectively translate theoretical frameworks into actionable learning experiences. This process ensures that vocational education moves beyond rote learning toward performance-based, experiential, and reflective teaching practices.

Furthermore, the integration of theory, practice, and innovation has been shown to be a driving force behind educational excellence. In the context of sports training, where skills application and situational learning are central, the combination of digital resources, field practice, and creative teaching strategies enhances both learning motivation and professional adaptability. The collaborative reform efforts at Tianjin Vocational College of Sports exemplify how educators, industry experts, and institutional leaders can jointly foster sustainable mechanisms for course and textbook co-development.

In conclusion, the pathway from curriculum to textbook represents not only a structural progression but also a paradigm shift in vocational education philosophy—from teacher-centered instruction to learner-centered, competence-oriented, and innovation-driven education. Through continuous alignment between educational objectives and industry needs, the development of "gold courses" and "gold textbooks" can effectively cultivate reflective, skilled, and forward-looking professionals, contributing to the modernization and high-quality development of vocational sports training education.

COMPETING INTERESTS

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REFERENCES

[1] Tyler R. Basic Principles of Curriculum and Instruction. Chicago: University of Chicago Press, 1949.
[2] Wheelahan L, Moodie G. Rethinking Skills in Vocational Education and Training: From Competencies to Capabilities. Sydney: NSW Board of Vocational Education and Training, 2011.
[3] Ministry of Education of the People's Republic of China. National Vocational Education Reform Implementation Plan. Beijing: MOE Press, 2019.
[4] Zhang Wei. Research on competency-based curriculum design in higher vocational education. Vocational and Technical Education, 2020(12): 45–49.
[5] Liu Jing. Modular curriculum reform and teaching innovation in Chinese vocational colleges. China Vocational and Technical Education, 2021(5): 22–28.
[6] Tomlinson B. Developing Materials for Language Teaching. 2nd ed. London: Bloomsbury, 2013.
[7] Hutchinson T, Torres E. The textbook as agent of change. ELT Journal, 1994, 48(4): 315–328. DOI: 10.1093/elt/48.4.315.
[8] Chen Xiaohong. The connotation and construction path of "gold textbooks" in vocational education. Education and Vocation, 2020(9): 34–39.
[9] Li Hong, Wang Rui. Characteristics and evaluation standards of "gold textbooks" in higher vocational colleges. Modern Education Management, 2021(6): 72–78.
[10] Tianjin Vocational College of Sports. Report on the Reform of "Gold Courses" in Sports Training. Tianjin: Internal Publication, 2023.

INNOVATION OF TOURISM MANAGEMENT CURRICULUM SYSTEM IN APPLICATION-ORIENTED UNIVERSITIES IN JILIN PROVINCE FACING THE NEW LIBERAL ARTS

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Abstract: In response to the requirements of the construction of new Liberal Arts , this paper investigated the current status of the tourism management curriculum system in application-oriented universities in Jilin Province. It diagnosed the core issues in the existing curriculum system regarding objectives, structure, content, and methods. An innovative "pyramid-style" new curriculum system, characterized by "value-led, cross-integration, and competency-based" approaches, was constructed. This provides a theoretical framework and practical paradigm for the reform of tourism management majors in similar universities.
Keywords: New Liberal Arts; Application-oriented universities; Tourism management; Curriculum system; Innovation

1 INTRODUCTION

In 2018, China officially proposed the concept of "New Liberal Arts", which plays an important role in the reform of traditional liberal arts teaching paradigms and teaching concepts in China[1]. In 2020, the Ministry of Education issued the "Declaration on the Construction of New Liberal Arts", which elevated China's construction of new liberal arts to a new height[2]. The construction of "New Liberal Arts" is a major strategic measure proposed by Chinese higher education in response to the global technological revolution, industrial transformation, and profound social transformation in the context of the new era. It is not a simple negation or repair of traditional humanities, but a systematic and revolutionary reconstruction involving ideas, models, content, and methods. Given the background of educational development, the construction of a new liberal arts program for tourism management majors in application-oriented universities is urgently needed[3].

2 CURRENT SITUATION INVESTIGATION

In order to accurately understand the current situation of the curriculum system of tourism management majors in application-oriented universities and test its compatibility with the requirements of the New Liberal Arts construction, this study selected five representative application-oriented universities in Jilin Province as research objects, including Jilin Engineering Normal University, Jilin Business and Technology College, Tonghua Normal University, the Tourism College of Changchun University and Changchun Guanghua University. Through text analysis of its talent cultivation program and in-depth interviews with teachers and students, the research results are systematically sorted and analyzed from three dimensions: curriculum objectives and structure, teaching content and methods, evaluation system, and faculty team. The aim is to reveal existing problems and provide a basis for subsequent curriculum system innovation.

2.1 In terms of Course Objectives and Structure

2.1.1 Consistency in course objective expression
In the 5 talent development plans surveyed, all texts mentioned "application-oriented", and some plans also mentioned "adapting to industry development" and "mastering modern technology". However, these goal statements generally lack specific, measurable, and actionable connotations that correspond to the core concepts of the New Liberal Arts. For example, there is no clear plan to include "interdisciplinary thinking" or "integrated innovation ability" as training objectives; For the specific meaning of "mastering modern technology", the vast majority of solutions still remain at the relatively outdated level of "tourism e-commerce" and "office software operation". This indicates that the training goal of many universities is still mainly to cultivate managers who master the traditional operational skills of tourism enterprises, and there is a clear lack of awareness in shaping industry leaders and entrepreneurs who can handle the integration of culture and tourism and digital transformation for the future.

2.1.2 Course structure with obvious platformization
The obvious diversification of course structure is the most core issue discovered in this survey. Although almost all universities have established modules for "general education courses," "subject foundation courses," "professional core courses," and "professional direction courses," their internal integration logic is very weak, with overlapping and fragmented content between courses, and interdisciplinary course content being severely marginalized. Research shows that only 2 out of 5 universities offer independent courses on "tourism big data analysis"; Only Tonghua Normal University has offered local cultural characteristic courses such as "Changbai Mountain Regional Tourism" special

practice and "Intangible Cultural Heritage Skills Training"; Interdisciplinary courses such as "Tourism Geographic Information System" and "Cultural Heritage and Tourism" have not been offered.

2.1.3 Insufficient modular design

The "problem oriented" and "personalized training" advocated by the New Liberal Arts require a highly flexible and modular curriculum structure. However, the current situation is that the course structure of the vast majority of universities is too rigid, with elective course credits generally accounting for less than 20%, and the elective course library is updated slowly, with serious homogenization of content, mostly conceptual introductions in traditional directions such as "exhibition tourism" and "health tourism", resulting in a single and rigid path for student knowledge construction.

2.2 In terms of Teaching Content and Methods

2.2.1 Delayed updating of teaching content

Through the analysis of talent training programs and core course syllabus for tourism management majors in five application-oriented universities in Jilin Province, it was found that the integration of new technologies such as cloud computing, big data, and artificial intelligence is low and superficial. More than 70% of the "Tourism Marketing" courses still revolve around traditional 4P theory, SWOT analysis, and questionnaire surveys as their core content. For new technology driven marketing paradigms such as social media marketing, user generated content, algorithm recommendations, and metaverse marketing, they only provide conceptual introductions and lack practical training based on real data platforms.

2.2.2 Teaching methods still primarily rely on lectures

Traditional teaching methods dominate, and teaching activities guided by ability building are scarce. The interview results show that over 80% of students believe that the main teaching method for their professional courses is for teachers to teach and students to listen. Although case-based teaching is widely adopted, most cases are outdated and the analysis process is superficial, often requiring teachers to provide standard answers rather than guiding students to engage in open thinking and exploration. This one-dimensional knowledge imparting model cannot effectively cultivate students' critical thinking, complex problem-solving skills, and teamwork abilities. Although all universities have set up practical activities such as internships and course design, there are very few truly project-based teaching applications that run through the curriculum.

2.2.3 Insufficient application of digital teaching resources

Most online teaching platforms such as "www.chaoxing.com" and "www.zhihuishu.com" in universities are mainly used as databases for publishing notifications, submitting assignments, and storing PPTs, and have not effectively supported the implementation of blended learning between online and offline. Lack of digital course resource packages specifically developed for core courses in tourism management, integrating industry data, simulation software, and interactive cases. This deprives innovation in teaching methods of important technological carriers, making it difficult to break through the limitations of time, space, and physical resources.

2.3 In Terms of Evaluation System and Faculty Team

2.3.1 Lack of a diversified curriculum evaluation system

In the assessment method of research courses, the average weight of final exams or course papers exceeds 70%. This evaluation method mainly tests students' memory and comprehension ability of isolated knowledge points, and cannot effectively evaluate their ability to integrate multidisciplinary knowledge to solve practical problems, innovation ability, teamwork and communication ability in complex and open real situations. Summative evaluation dominates and is difficult to measure the interdisciplinary comprehensive ability advocated by the New Liberal Arts. The evaluation subject is almost a single teaching teacher, and self-evaluation and peer evaluation by industry mentors and students are rarely included and have extremely low weight.

2.3.2 Teacher's knowledge structure needs improvement

More than 85% of the tourism management teachers surveyed in universities hold doctoral degrees in management, economics, or geography, while there are very few teachers with interdisciplinary degrees or long-term experience in computer science, data science, design, sociology, environmental science, and other fields. Although there is a requirement for "Double-certificated Teacher", most of them are obtained through short-term training or certification, lacking a mechanism for long-term and in-depth on-the-job training in cultural and tourism technology enterprises, data companies, planning and design institutes, etc. This makes it difficult for teachers to bring the latest industry practices, technological trends, and real projects into the classroom.

2.3.3 Difficulties in Building Interdisciplinary Teaching Teams

Although some universities have attempted to promote cross college collaboration, such as inviting teachers from the School of Computer Science to teach tourism majors or collaborating on course offerings. However, due to the barriers between colleges, the heavy workload of preparing for new courses, and the lack of common interest driving points and effective collaboration platforms, such cooperation mostly remains in lecture style sporadic participation, making it difficult to form a stable interdisciplinary teaching team responsible for course design and full teaching. The hired industry mentors mainly focus on giving lectures, and their wisdom and resources have not been systematically integrated into core teaching processes such as curriculum development, project guidance, and performance evaluation.

3   COUNTERMEASURES AND SUGGESTIONS

To overcome the core challenges of strict disciplinary barriers, shallow integration of industry and education, and weak innovation capabilities, it aims to construct a new curriculum system for tourism management majors that is oriented towards New Liberal Arts and rooted in application-oriented approaches[4].

3.1 Target Dimension Enhancement and Structural Reorganization

The primary task of curriculum system innovation lies in the reconstruction of top-level design. The study proposes to construct a "pyramid shaped" curriculum system consisting of a value literacy layer, a cross core layer, and an open expansion layer, to achieve the transformation from disciplinary logic to growth logic.

3.1.1 Consolidate the foundation of general education and strengthen the cultural and tourism value literacy

This layer corresponds to the general education module, aiming to solve the problem of the disconnect between general education and professional education[5]. Add new compulsory modules for liberal arts fundamentals, such as offering courses like "Fundamentals of Digital Literacy and Data Analysis" or "Fundamentals of AI Application Technology" to replace traditional "Fundamentals of Computer Science", covering courses such as Python basics, data visualization, and AI ethics. These courses focus on enhancing students' humanistic and technological literacy necessary for adapting to the development of modern tourism industry. Integrating cultural and tourism knowledge into general education courses, creating a cultural and tourism oriented elective module, aiming to build a bridge between the disciplines of literature, science, engineering, art, and tourism, guiding students to examine tourism phenomena from a multidisciplinary perspective, and achieving an organic connection between general education and professional education.

3.1.2 Breaking down disciplinary barriers and reshaping the core of professional competence

This layer is the core of the reform, aimed at solving the problem of linear extension and outdated content in professional courses[6]. Thoroughly breaking the boundaries of traditional courses such as Tourism Economics, Marketing, and Travel Agency Management, and reconstructing interdisciplinary competency modules around the core value chain of the cultural and tourism industry. The module of cultural tourism integration and product innovation integrates knowledge from cultural studies, management, and design. The core course "Cultural Tourism Integration Product Planning and Practice" will replace related traditional courses. Students need to complete a full process project from cultural resource research, IP extraction, creative design to business model construction, such as "designing an immersive tourism experience product for Changbai Mountain intangible cultural heritage".

3.1.3 Connecting with the forefront of the industry and empowering students' individual development

This layer aims to solve the problems of insufficient modularity and single path, and empower students with the right to make independent choices[7]. Establish a "micro specialty" direction. Based on industry trends, micro majors such as "Digital Cultural Tourism Marketing", "Digital Protection of Cultural Heritage", and "Smart Scenic Area Planning and Management" will be established. Each micro major consists of 3-4 courses, and students can choose to take them according to their interests and career plans. Open cutting-edge dynamic workshops and regularly invite industry experts to hold short-term workshops to ensure that teaching content is synchronized with the forefront of the industry. Promote interdisciplinary project practice, encourage students to form teams across disciplines, participate in teacher's horizontal projects and subject competition projects, and their achievements can be exchanged for credits at this level.

3.2 Content Updates and Mode Changes

3.2.1 Promote the dynamic and cutting-edge iteration of teaching content

Establish an "Industry Enterprise Curriculum Resource Library" and a "Real Project Case Library". Revise the teaching syllabus based on the latest developments in the industry. Collaborate with well-known local cultural and tourism enterprises to develop teaching cases based on real projects and data, and update them annually. Every academic year, professional teachers and industry mentors jointly review and revise the curriculum outline, timely incorporating new technologies, new formats, and new standards. Deeply integrating technological tools and local cultural context, in the course of "Tourism Marketing", the teaching content must cover practical skills such as social media data analysis tools and short video creation.

3.2.2 Fully establish the core position of project-based learning

The project-based teaching method runs through the core competency module courses, with one or more real projects that run through the semester as the backbone. Students collaborate in groups and go through the entire process of requirement analysis, technology selection, functional design, prototype development, and solution presentation. Based on the requirements of project-based teaching, the role of teachers needs to shift from lecturers to project mentors and resource coordinators. In terms of teaching management, detailed project task books, team collaboration tools, and process evaluation criteria need to be provided to ensure that project-based teaching does not become a mere formality and effectively enhances students' ability to solve complex problems.

3.2.3 Deepening the integration of digitalization and industry education in teaching scenarios

Build a smart tourism virtual simulation center, with a focus on investing in the construction or upgrading of training platforms with functions such as big data analysis, VR/AR experience, hotel and scenic area operation simulation. Enable students to make decisions, operate, and handle crises in a highly simulated environment, reducing practical costs and enhancing learning efficiency. Promote dual teacher co teaching and embedded industry teaching, deepening

the participation of enterprise mentors from lectures to joint project design, teaching, guidance, and grading. For example, in the project defense stage, the grading weight of enterprise mentors can account for 50%, directly testing the market value and feasibility of student proposals. At the same time, extending the classroom to the enterprise site and conducting on-site teaching at the Industry-University-Research Collaboration Base[8].

3.3 Evaluation Reform and Teacher Reshaping

3.3.1 Building a multi-dimensional evaluation system

Strengthen process evaluation, downplay final assessment, reduce the weight of core course final exams to 30% to 40%, and distribute the remaining 60% to 70% in various stages of the project process, such as project proposal, mid-term defense, team contribution, work log, and final result presentation. Promote diverse subjects and methods. In addition to exams, the evaluation method vigorously promotes project reports, design proposals, roadshow defenses, portfolios, practical operations, etc., with a focus on testing comprehensive abilities such as knowledge integration, innovative thinking, and teamwork. To this end, it is necessary to develop refined evaluation metrics for different dimensions of abilities, so that evaluations can be based on evidence.

3.3.2 Promote the transformation of the teaching staff

Implement a teacher knowledge update plan, support teachers to visit universities at home and abroad, focus on data science, digital humanities and other fields, or go to top cultural and tourism technology enterprises for full-time on-the-job training for more than six months, and require teachers to update their knowledge structure. Enhance teachers' teaching abilities, regularly organize specialized workshops such as "PBL Teaching Design" and "Blended Gold Course Construction", and incorporate teaching reform achievements into the professional title evaluation and performance assessment system. Establish an interdisciplinary teaching team [9], clarify the workload accounting and achievement sharing mechanism for interdisciplinary courses. Build a teaching community consisting of teachers from multiple disciplinary backgrounds around the core curriculum modules, implementing collective lesson preparation, collaborative teaching, and joint guidance.

3.3.3 Establish a continuous improvement loop

Establish a "Curriculum Quality Committee" composed of professional leaders, backbone teachers, student representatives, and industry experts, to systematically collect teaching process data, student feedback, graduate surveys, and employer evaluations every semester, diagnose the implementation effect of the curriculum system, and dynamically improve the curriculum objectives, content, methods, and evaluations based on this, ensuring that the curriculum system remains dynamic and continues to move towards the construction goals of the New Liberal Arts.

4   CONCLUSION

Based on the research on the current situation and innovative construction of the curriculum system for tourism management majors in application-oriented universities in Jilin Province, it is concluded that the current curriculum system has systematic problems such as goal convergence, diversified structure, lagging content, and single evaluation. To achieve this, it is necessary to break through disciplinary barriers, construct a new "pyramid" curriculum system, and achieve a fundamental transformation from disciplinary logic to growth logic through systematic innovation in goal upgrading and structural restructuring, content updating and mode transformation, evaluation reform, and teacher reshaping. This system can effectively enhance students' interdisciplinary thinking and practical innovation abilities, providing a reference path for cultivating compound talents that adapt to the development of the cultural and tourism industry.

COMPETING INTERESTS

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REFERENCES

[1] WU Y. Accumulate momentum, accumulate momentum, plan momentum, recognize changes, adapt to changes, and comprehensively promote the construction of New Liberal Arts. Conference on the Construction of New Liberal Arts, 2020.

[2] Shang X, Zhu J, Ma M. A review and trend outlook of research in the field of New Liberal Arts in China. Journal of Library and Information Science, 2022, 7(07):56-66.

[3] Tian L, Sui P, Liu L. Cognition and Reconstruction of Undergraduate Curriculum System in Tourism Management. China University Teaching ,2023(05):28-34.

[4] Tian L, Liu L. Construction of Tourism Higher Education Curriculum System under the Background of New Liberal Arts. Tourism Tribune, 2022, 37(08):3-5.

[5] Cheng L K, Wei X. Boya education in China: Lessons from liberal arts education in the U.S. and Hong Kong. International Journal of Educational Development, 2021, 84(2):102419.

[6] Huang Z, Huagn R, Hou G. The reform of undergraduate curriculum and "Golden Courses" construction in tourism management specialty under the background of New Liberal Arts. Tourism Tribune, 2020, 35(10): 83-95.

[7] Zeng L. Construction of Curriculum System for Foreign-related Digital Trade Legal Talent Training in the New Liberal Arts Context. Theory and Practice of Social Science, 2022.

[8] Okano H, Urushihara S. Curriculum Innovation Utilizing High School and University Connection System of National Institute of Technology. Journal of JSEE, 2021, 69(2):2_109-2_113.

[9] Kato T , Fujioka J, Hori J, et al. Education System for Achieving SDGs : Proposal for The New Core Curriculum to Enable Engineering Education in Collaboration with Humanities in KOSEN, Based Within a Historical Context. National Institute of Technology, Ishikawa College Bulletin, 2020, 52:1-10.

ENHANCING ANALOG ELECTRONICS UNDERSTANDING FOR NON-ENGINEERING PHYSICS MAJORS: A PROJECT-BASED LEARNING APPROACH FROM PN JUNCTION TO AMPLIFIER

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Abstract: Around the world, non-engineering students often struggle with introductory electronics courses, perceiving analog electronics in particular as abstract, fragmented and difficult to apply in practice. This challenge is acute in service courses such as *Fundamentals of Electrical and Electronic Technology* for physics majors, which are expected to support later work in measurement, control and experimental design. To address these issues, this study redesigned the analog electronics unit into a concentrated teaching module and embedded a large project based on project-based learning (PBL). The module is structured along a coherent conceptual trajectory "from PN junction to NPN transistor to small-signal amplifier", using current–voltage characteristics as a unifying representational thread to enhance conceptual coherence. A quasi-experimental design was adopted with three cohorts of undergraduate physics majors (N = 353) at a comprehensive university in China over three academic years (2020–2022). The 2020 cohort (one class, n = 51) received conventional fragmented instruction and served as the control group, whereas the 2021 and 2022 cohorts (six classes, n = 302) experienced the reformed instruction and formed the experimental group. Data were collected from final examination scores, including a dedicated subset of items on analog electronics, supplemented by project artefacts and student feedback. Descriptive statistics and independent-samples *t*-tests were used to compare the cohorts. Students in the experimental group scored on average 5.5 points higher on the overall exam and 2.9 points higher on the analog electronics subscore than those in the control group; pass rates also increased from 88.0% to about 95.0% overall and from 74.0% to about 85.5% for the analog items ($p < .001$; Cohen's $d \approx 1.21$ for overall scores and 0.96 for analog subscores). The findings suggest that a concentrated, conceptually coherent analog electronics module combined with a substantial PBL project can effectively enhance non-engineering students' understanding and performance in analog electronics. The study offers implications for the redesign of service electronics courses worldwide, particularly in programmes where students possess strong physics backgrounds but limited prior experience with circuit design.
Keywords: Project-based learning; Analog electronics; PN junction; Bipolar junction transistor; Non-engineering majors; Teaching reform

1 INTRODUCTION

In many countries, introductory electronics courses play a pivotal role in preparing students for modern scientific and technological work. Yet for non-engineering students—such as physics, chemistry or mechanical majors—analog electronics is frequently perceived as abstract, mathematically demanding and removed from their primary disciplinary interests. International research has documented persistent difficulties[1-3] in understanding non-linear devices, operating regions and biasing, as well as a tendency for students to rely on rote manipulation of formulas rather than conceptual reasoning[4-5]. These challenges are particularly salient in service courses that must support later work in measurement, instrumentation and control, while competing for limited curriculum time.

The course *Fundamentals of Electrical and Electronic Technology* offered to non-engineering physics majors at a comprehensive university in China exemplifies this broader challenge. While the course is intended to provide essential foundations in circuits, analog electronics and digital electronics, students often report that the analog electronics component feels fragmented and disconnected from both their prior physics knowledge and their future laboratory needs. Traditional instruction presents PN junctions, diodes, bipolar junction transistors (BJTs) and amplifier circuits as separate topics distributed across the semester, with limited explicit connections and mainly verification-type laboratory work. Under such conditions, students may pass exams yet still lack a coherent mental model that links device physics to circuit behaviour and practical design.

Existing research in engineering and electronics education has highlighted the importance of conceptual understanding and authentic, practice-oriented learning activities. Inductive and project-based learning (PBL)[6-8] approaches can foster deeper engagement and integration of knowledge. For non-electrical physics majors, however, the starting point of instruction is particularly crucial. These students typically have strong preparation in fundamental physics and are accustomed to reasoning in terms of microscopic mechanisms, models and physical pictures. At the same time, they may feel uncomfortable with abstract circuit symbols and "black-box" engineering components.

This study therefore explores a teaching reform that explicitly aligns analog electronics instruction with non-electrical physics majors' cognitive strengths. The reform has two key features. First, the analog electronics content is reorganized

into a concentrated module delivered over a relatively short time window, rather than being distributed sporadically throughout the semester. The module is structured around a coherent conceptual trajectory "from PN junction to NPN transistor to small-signal amplifier", using device current–voltage (I–V) characteristics as an integrative thread. Second, a large project based on PBL is embedded into this module. Students work in small groups to design, simulate, implement and test a small-signal amplifier using an NPN transistor, thereby applying the concepts of PN junctions, transistor operating regions and biasing conditions in an integrated way.

A quasi-experimental design was adopted with three cohorts of physics majors taking the course between 2020 and 2022. The 2020 cohort serves as the control group with conventional fragmented instruction, while the 2021 and 2022 cohorts form the experimental group with the reformed module and project. Exam data and student feedback are analysed to investigate the impact of the reform.

The study is guided by the following research questions:

• RQ1: To what extent does the concentrated analog electronics module combined with PBL improve non-engineering physics majors' conceptual understanding of PN junctions, transistors and amplifier circuits?

• RQ2: How does the reformed instruction affect students' engagement with and perceptions of the analog electronics component of the course?

• RQ3: How does the reformed instruction influence students' ability to troubleshoot and solve novel problems in analog electronics, as reflected in examination performance and project work?

By addressing these questions, the paper contributes to the literature on PBL and electronics education in three ways. First, it provides an example of how a foundational analog electronics module can be redesigned around a coherent conceptual trajectory that is accessible to non-electrical students. Second, it offers empirical evidence on the effectiveness of integrating a large project into a concentrated module in a service course. Third, it discusses practical considerations and constraints that may inform similar reforms in other institutions and disciplines.

2 LITERATURE REVIEW

2.1 Project-Based Learning in Engineering and Electronics Education

Project-based learning has been widely promoted as an effective approach in engineering and STEM education. In PBL, students work in teams on extended tasks that require them to apply knowledge and skills to design and implement artefacts or solutions. Reviews of inductive and project-based methods in engineering education report positive effects on student motivation, conceptual understanding, problem-solving skills and ability to integrate knowledge across topics[9-10].

In electronics and circuit courses specifically, PBL has been used to make content more engaging and meaningful by situating learning in the context of real or realistic design projects. Studies report that when students design and build circuits such as audio amplifiers, power supplies or embedded systems, they are more likely to appreciate the relevance of theory and to develop practical troubleshooting skills. Project-oriented problem-based learning variants have also been implemented in analog electronics courses, where projects are decomposed into stages such as requirement analysis, schematic design, simulation, printed circuit board layout and hardware implementation. These implementations highlight the importance of scaffolding, clear milestones and alignment between project tasks and course learning outcomes.

However, much of the existing literature focuses on electrical and electronics engineering majors[11-13]. The projects are often technically demanding and assume substantial prior knowledge of circuit theory and device physics. There is still relatively limited research on how PBL can be adapted for non-electrical cohorts, such as physics majors taking a service electronics course, who may have strong physics backgrounds but limited exposure to circuit design.

2.2 Conceptual Understanding in Analog Electronics

Research on student learning in electric circuits and analog electronics has documented persistent conceptual difficulties even after formal instruction. Students often struggle to understand the behaviour of non-linear devices such as diodes and transistors, the role of operating regions and the rationale for biasing networks. In many cases, students can manipulate circuit equations without a clear sense of the underlying device physics or the qualitative behaviour of the circuit[14].

Several studies suggest that a key challenge lies in connecting microscopic device models to macroscopic circuit behaviour. When devices are treated primarily as idealised symbols with a few parameters, students may lack the grounding needed to reason flexibly about new configurations or operating conditions. For physics majors, who are used to thinking in terms of carrier transport, band diagrams and physical mechanisms, instruction that does not explicitly build on these strengths can feel unsatisfying and "unphysical"[15].

Recent work has called for a more integrated approach that connects solid-state physics concepts with circuit applications, especially in courses that attract both physics and engineering students. Such an approach emphasises visual representations such as I–V curves, energy band diagrams and operating-region maps as tools for reasoning, rather than focusing exclusively on algebraic formulas. It also argues for sequencing content in a way that supports a coherent conceptual trajectory, for example, from PN junction to diode circuits, then to transistor structure and operation, and finally to amplifier design.

2.3 Service Courses for Non-Electrical Majors

Service courses in electrical and electronic technology occupy a challenging position in many curricula. They must provide sufficient depth to support later work in instrumentation, control and data acquisition, while also respecting the limited time and varying backgrounds of students from other disciplines. For non-electrical physics majors, service electronics courses are expected to complement laboratory and experimental courses, providing the foundations needed to design and interpret measurements and to communicate effectively with electronics specialists.

However, service courses are sometimes designed by directly "shrinking down" versions of courses intended for electrical engineering majors, without sufficiently adapting content, examples and pedagogy to the needs of non-electrical students. This can exacerbate perceptions of irrelevance and difficulty. There is a need for more studies that explicitly tailor service electronics courses to the cognitive profiles, future needs and disciplinary cultures of specific non-electrical cohorts, and that examine the impact of such tailoring on learning outcomes.

2.4 Contribution of the Present Study

Against this backdrop, the present study contributes by designing and evaluating a teaching reform in a service analog electronics module targeted at non-electrical physics majors. It combines two elements that have each shown promise in prior work—PBL and conceptually coherent sequencing—but adapts them to a context where students have strong physics backgrounds yet limited prior experience with circuit design. By analysing three cohorts over three years, the study provides empirical evidence on how such a reform influences exam performance, pass rates and students' engagement with analog electronics.

3   METHODOLOGY

3.1 Context and Participants

The study was conducted in the course *Fundamentals of Electrical and Electronic Technology* offered by the Department of Physics at Jiangsu Second Normal University, a comprehensive university in China. The course is a required foundation module for physics majors (including general and teacher education tracks) and introduces basic concepts of circuits, analog electronics and digital electronics. The analog electronics unit covers PN junctions, diodes, BJTs and basic amplifier circuits.

The participants were three cohorts of undergraduate physics majors who took the course between 2020 and 2022. In total, 353 students from seven intact class groups were included in the analysis: one class in the 2020 cohort and three classes in each of the 2021 and 2022 cohorts. The 2020 cohort received conventional instruction and served as the control cohort. The 2021 and 2022 cohorts received the reformed instruction and thus formed the experimental cohort (Table 1).

Table 1 Cohorts, Class Groups and Sample Sizes for the Control and Experimental Groups

Year	Class name	Sample size(N)	Teaching condition
2020	Physics General Class (Teacher Education)	51	Control
2021	Physics General Class 1 (Targeted Teacher Education)	46	Experimental
2021	Physics General Class 2 (Targeted Teacher Education)	48	Experimental
2021	Physics General Class (Teacher Education)	60	Experimental
2022	Physics General Class 1 (Targeted Teacher Education)	45	Experimental
2022	Physics General Class 2 (Targeted Teacher Education)	45	Experimental

3.2 Instructional Design

In the conventional version used with the 2020 cohort, the analog electronics content was taught as four separate topics—PN junctions and diodes, BJT structure and characteristics, biasing, and amplifier circuits—distributed intermittently across the 16-week semester. Each topic was covered in approximately 4 class hours, interspersed with content on basic circuits and digital electronics. Laboratory exercises mainly involved confirmation of textbook circuits. There was no extended project activity.

In the reformed version implemented with the 2021 and 2022 cohorts, the analog electronics content was reorganised into a concentrated module delivered over approximately five consecutive weeks in the middle of the semester, accounting for 20 class hours (10 sessions × 2 hours). The module followed a coherent trajectory "from PN junction to NPN transistor to small-signal amplifier" and used device I–V characteristics as an integrative representational tool. The main steps were:

1. PN junction physics and I–V characteristics (4 hours);

2. Diode behaviour and simple rectifier/limiter circuits (2 hours);
3. NPN transistor as two coupled PN junctions and its operating regions (4 hours);
4. Transistor biasing and small-signal modelling (4 hours);
5. Single-stage common-emitter amplifier design and analysis (6 hours, integrated with project activities).

The PBL component took the form of a large project entitled "Design and implementation of an NPN transistor-based small-signal amplifier", typically a simple microphone preamplifier. Students worked in groups of 3–4 members over the same five-week period. Each group was encouraged to assign informal roles (e.g., circuit designer, simulation analyst, measurement coordinator, documentation writer), while rotating tasks to ensure that all members engaged with both analysis and hands-on work. The project was structured into four milestones:

(1) requirement clarification and review of device concepts;
(2) preliminary circuit design and bias calculations;
(3) simulation and prototype testing on a breadboard;
(4) refinement and final reporting.

The instructor met each group at least once per week during scheduled lab or discussion sessions and provided additional consultation upon request. Short just-in-time mini-lectures were offered when recurring issues were identified (e.g., misunderstanding of transistor operating regions or coupling capacitor effects). As shown in Figure 1, this is the most common NPN common-emitter small-signal amplifier circuit encountered in analog-circuit learning. It employs a voltage-divider bias structure: the input terminal is connected to the signal source via a coupling capacitor, and the output terminal drives a load resistor. uilding on the structure and pedagogical logic of the voltage-divider-biased common-emitter amplifier described above, this study adopts the circuit as the core project task. Around its design, simulation, and measurement phases, we systematically collected multidimensional data on students' conceptual understanding, problem-solving, and teamwork; the specific instruments and procedures are detailed in the next section.
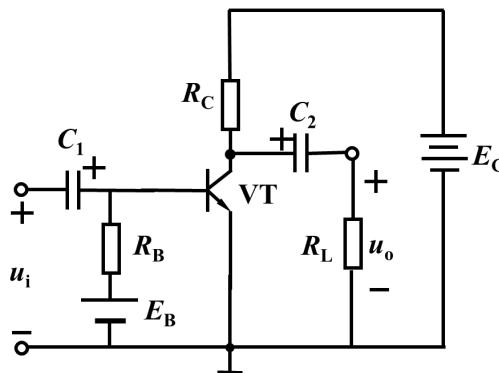
Figure 1 Simplified Schematic of a Typical Student-Designed NPN Transistor Small-Signal Amplifier used in the Project

3.3 Instruments and Data Collection

Multiple data sources were used to evaluate the impact of the teaching reform.

First, achievement data from the final examination were used to assess students' conceptual understanding and application of analog electronics. The final exam contained a subset of items specifically targeting PN junctions, transistor operating regions, biasing and amplifier analysis and design. For each student, two scores were extracted: (1) the overall final exam score, and (2) an analog electronics subscore corresponding to the relevant items. The structure and difficulty of the final exam were kept comparable across the three cohorts.

Second, for the experimental cohorts (2021 and 2022), group project performance was evaluated using an analytic rubric with four main dimensions:

(1) Circuit design and biasing (30%) – correctness of the topology, appropriateness of the chosen operating point, and justification of component values;
(2) Simulation and experimental implementation (30%) – completeness and correctness of simulation results, successful hardware implementation, and quality of measurement and troubleshooting;
(3) Conceptual explanation (20%) – clarity and depth of explanations linking PN junction and transistor physics to circuit behaviour in the written report;
(4) Reporting and teamwork (20%) – organisation and clarity of the written report and oral presentation, and evidence of balanced participation across group members.

The final project score for each student combined the group mark with a brief peer- and self-evaluation, in which students indicated the relative contribution of each member. This procedure was used to discourage free-riding and to better reflect individual engagement.

Third, student feedback was collected through brief questionnaires and informal comments, focusing on perceived difficulty, interest, perceived usefulness and perceptions of coherence ("from PN junction to transistor to amplifier"). Although these data are used mainly qualitatively in this paper, they provide context for interpreting the exam results.

All exam and project scores were anonymised before analysis. Participation in feedback activities was voluntary and

had no impact on course grades.

3.4 Data Analysis

Quantitative data from the final examination were analysed using both descriptive and inferential statistics. For each cohort and class group, means and standard deviations were computed for overall exam scores and for the analog electronics subscores, along with pass rates (score ≥ 60).

To compare the control and experimental cohorts, independent-samples *t*-tests were conducted on the overall exam scores and on the analog subscores. Additional *t*-tests were used to compare the 2021 and 2022 experimental cohorts to explore possible iterative improvement effects. Effect sizes were estimated using Cohen's *d*.

In this paper, the focus is on the comparison between the 2020 control cohort (n = 51) and the combined 2021–2022 experimental cohorts (n = 302). The reported *t*-statistics are $t = -8.00$ for overall exam scores and $t = -6.35$ for analog electronics subscores (two-tailed tests, $p < .001$). From these statistics and sample sizes, Cohen's *d* values of approximately 1.21 (overall) and 0.96 (analog) were obtained, indicating large effect sizes. Qualitative comments from student feedback and project reports were subjected to a simple thematic analysis to identify recurring themes related to conceptual understanding, perceived coherence of the "PN junction–transistor–amplifier" trajectory, and experiences with the project.

4   RESULTS

4.1 Descriptive Statistics

Table 2 summarises key descriptive statistics for the control and experimental groups, including overall exam means, pass and excellent rates, and analog electronics subscores and pass rates. The control cohort (2020, n = 51) achieved a mean overall score of 82.0, with an overall pass rate of 88.0% and an excellent rate (≥ 85) of 16.0%. The mean analog electronics subscore for this cohort was 18.5, with a pass rate of 74.0% on the analog items.

The combined experimental cohorts (2021–2022, n = 302) obtained a higher weighted mean overall score of 87.53, with a pass rate of 95.03% and an excellent rate of 29.14%. The weighted mean analog electronics subscore increased to 21.37, and the pass rate on the analog items rose to 85.49%. In relative terms, the experimental group outperformed the control group by 5.53 points (6.7%) on the overall score and by 2.87 points (15.5%) on the analog subscore.

Table 2 Descriptive Statistics for Overall Exam Scores and Analog Electronics Subscores in the Control and Experimental Groups

Indicators	Control Group (2020 Cohort)	Experimental Group (2021–2022 Cohorts)	Difference	Percentage Difference
Total Number of Students	51	302	—	—
Overall Exam Score (Mean)	82.00	87.53	+5.53	+6.7%
Overall Exam Pass Rate	88.00%	95.03%	+7.03%	+8.0%
Overall Exam Excellent Rate	16.00%	29.14%	+13.14%	+82.1%
Analog Electronics Subscore (Mean)	18.50	21.37	+2.87	+15.5%
Analog Electronics Pass Rate	74.00%	85.49%	+11.49%	+15.5%

Table 3 consolidates these findings: across the six experimental class groups, overall means varied from 84.1 to 90.3, pass rates from 91.11 % to 98.28 %, and excellence rates from 14.58 % to 39.66 %; corresponding analog sub-scores ranged from 19.75 to 23.00, with sub-score pass rates between 79 % and 92 %. Although inter-class differences are evident, every experimental section equalled or surpassed the control cohort on both global and analog-specific metrics.

Table 3 Class-Level Descriptive Statistics for all Seven Classes

Dependent Variable	t-Value	p-Value	Mean Difference (Experimental – Control)	Statistical Significance (α = 0.05)
Overall Exam Score	-8.0007	0.0000	5.53	Significant
Analog Electronics Subscore	-6.3513	0.0000	2.87	Significant

4.2 Overall Exam Performance: t-Test Results

As illustrated in Table 4 and Figure 2, independent-samples t-tests were conducted to compare the overall end-of-semester performance between the 2020 control cohort and the pooled 2021 – 2022 experimental cohorts. Students in the experimental group scored on average 5.5 points higher on the overall final examination than students in the control group (87.5 vs. 82.0). The overall pass rate also increased from 88.0% in the control cohort to approximately 95.0% in the experimental cohorts.

The difference in overall scores between the control and experimental groups was statistically significant, $t = -8.00$, *p*

< .001, with a large effect size (Cohen's $d \approx 1.21$). This indicates that, beyond sampling fluctuations, the reformed instruction was associated with a substantial improvement in overall course achievement.

Table 4 Independent-Samples t-Test Results Comparing Control and Experimental Groups on Overall Exam Scores and Analog Electronics Subscores

Dependent Variable	Control Group (M ± SD)	Experimental Group (M ± SD)	n_1/n_2	t-Value
Overall Exam Score	82.00 ± 6.91	87.53 ± 6.91	51/302	-8.0007
Analog Electronics Subscore	18.50 ± 4.52	21.37 ± 4.52	51/302	-6.3513
Dependent Variable	Degrees of Freedom (df)	p-Value	Cohen's d (Effect Size)	Statistical Significance ($\alpha = 0.05$)
Overall Exam Score	351	0.0000	1.40	Significant
Analog Electronics Subscore	351	0.0000	1.11	Significant
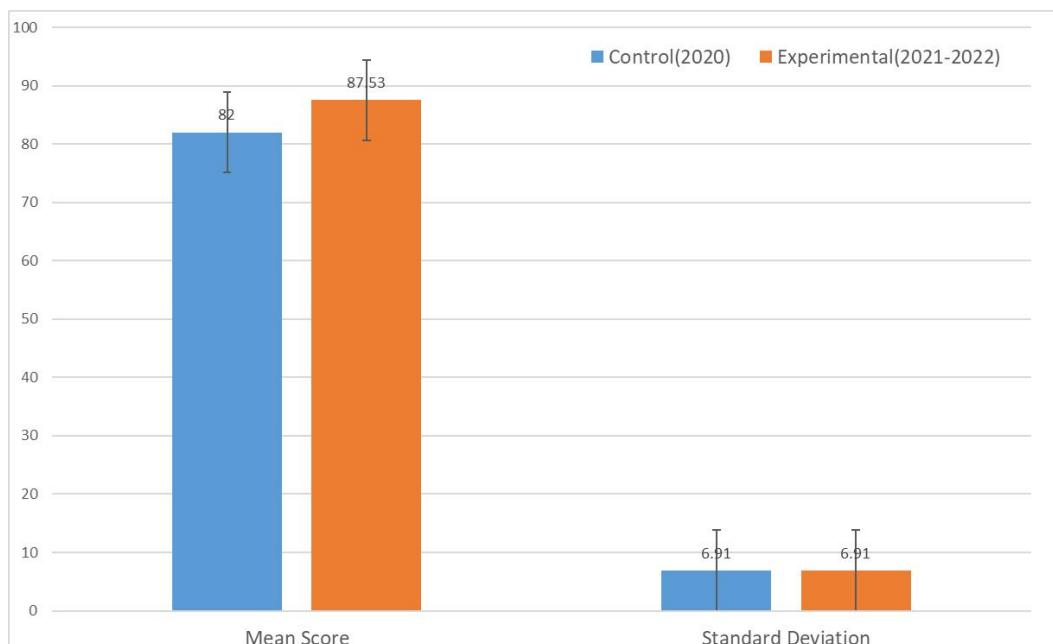
Figure 2 Comparison of Mean Overall Exam Scores for the Control (2020) and Experimental (2021–2022) Groups, with Error Bars Indicating Standard Deviations

4.3 Performance on Analog Electronics Items: t-Test Results

As depicted in Figure 3, given that the present study centres on the analogue-electronics unit, particular attention was paid to students' performance on the examination items covering PN junctions, transistor operation and small-signal amplifier circuits. The experimental cohorts achieved a mean analogue-electronics sub-score of 21.37, compared with 18.50 for the control cohort — an average gain of 2.87 points. The corresponding pass rate rose from 74.0 % to approximately 85.49 %. An independent-samples t-test indicated that this difference was statistically significant, t = – 6.35, p < .001, with a large effect size (Cohen's d ≈ 0.96). Class-level mean analogue sub-scores within the experimental groups ranged from 19.75 to 23.00, demonstrating that the positive impact of the reform was robust across different class types.
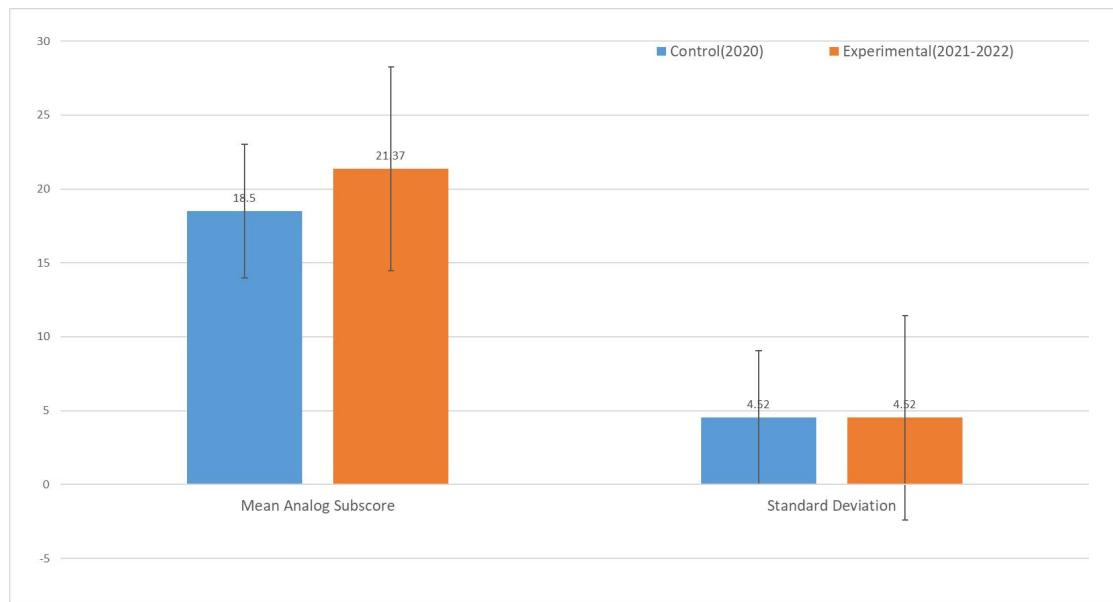
Figure 3 Comparison of Mean Analog Electronics Subscores for the Control (2020) and Experimental (2021–2022) Groups

Considering the two experimental cohorts separately, the 2021 classes (N = 154) achieved a weighted mean analog subscore of about 20.4, with an analog pass rate of 81.6%. The 2022 classes (N = 148) reached a higher mean analog subscore of about 22.4 and a pass rate of 89.6%. This pattern suggests not only a clear improvement relative to the 2020 control cohort, but also further refinement of teaching practice and project implementation between 2021 and 2022.

5   DISCUSSION

5.1 From Physical Principles to Engineering Applications

The quantitative results indicate that students exposed to the reformed module achieved higher overall scores and substantially better performance on the analog electronics items than those in the traditional cohort. These gains can be interpreted in light of the way the reformed module aligns with non-electrical physics majors' cognitive strengths.

Most students in this programme have a solid grounding in fundamental physics and are accustomed to reasoning in terms of microscopic mechanisms, qualitative models and energy band diagrams. At the same time, they often report feeling uncomfortable with abstract circuit symbols and black-box engineering components. By starting from the PN junction as a familiar physical object, the reformed module meets students where they are. The PN junction can be explained using concepts such as band structure, majority and minority carriers, diffusion and drift, depletion regions and built-in potentials. In this way, the single-direction conduction of a diode and the formation of a potential barrier are not presented as mere properties of a symbol, but as natural consequences of carrier transport and energy band bending.

The transition from the PN junction to the NPN transistor then becomes a logical extension rather than a conceptual leap. When students see an NPN transistor as two coupled PN junctions plus a controlled current path, they can analyse the roles of the emitter–base and collector–base junctions under different biasing conditions. Discussions of cutoff, active and saturation regions are anchored in whether each junction is forward- or reverse-biased and in how carriers are injected and collected. In this view, the current amplification relationship $I_C \approx \beta I_B$ $I\_BIC \approx \beta I\_BIC \approx \beta IB$ is no longer perceived as a mysterious empirical rule, but as a macroscopic description of underlying transport phenomena. This directly addresses students' implicit question of where amplification comes from.

Once this microscopic understanding is established, the step from device to circuit is smoother. The design of a single-stage amplifier is framed as creating the appropriate external conditions for the transistor so that it can operate in its intended region. The necessity of DC biasing and the choice of a quiescent operating point in the active region follow naturally from the recognised non-linearity of the transistor's characteristics. For students who understand the transistor's I–V behaviour, bias networks and coupling capacitors are no longer arbitrary topologies to be memorised; they are purposeful mechanisms for placing and maintaining the device in a suitable operating regime.

5.2 Addressing Core Difficulties of Non-Electrical Majors

The reform also appears to address two frequently reported difficulties among non-electrical majors: not seeing the relevance of analog electronics and perceiving the content as excessively abstract and memorisation-driven. The PN junction → transistor → amplifier → project trajectory provides a continuous learning path in which each step has an evident role. Students first gain a physically satisfying explanation of basic semiconductor behaviour, then see how combining PN junctions yields a controllable device, and finally experience how this device is embedded in a functional circuit.

This progression can create repeated "aha" moments: understanding the PN junction, explaining how a transistor works, designing a bias network to make it amplify and ultimately building a circuit that makes a real-world signal larger. Such experiences form a strong source of intrinsic motivation. Instead of being asked to memorise formulas and standard circuits whose purpose is opaque, students are invited to derive and justify them. For example, when students appreciate the temperature dependence of saturation current and current gain, they can reason about why the bias point may drift with temperature and why stabilising measures are needed. This shift from passive memorisation to active derivation reduces cognitive load and better prepares students to handle novel situations beyond textbook examples.

Furthermore, the reform supports the development of what might be called a system and interface perspective. Many physics majors will later use electronic modules as part of larger experimental or engineering systems rather than design complex circuits from scratch. By constructing a simple but complete amplifier themselves, they learn to think about a module in terms of input and output characteristics, power supply requirements, loading effects and constraints. This prepares them to communicate with electronics specialists and to specify realistic requirements when selecting or integrating off-the-shelf modules in their future work.

From a cognitive perspective, the coherent trajectory reduces fragmentation by continually revisiting a small set of core representations (I–V curves, operating-region diagrams) in progressively richer contexts. From a motivational perspective, the project creates a sequence of "aha" moments in which students can see their abstract understanding materialise in a working circuit. From a competence perspective, the need to diagnose distortion, saturation and bias drift fosters systems thinking and problem-solving skills that go beyond routine calculation.

5.3 The Integrative Role of the Large Project

The large project plays a central role in consolidating and extending students' understanding. In the present implementation, a typical project theme is a simple microphone preamplifier. To complete such a project, students must bring together all prior content: they need PN junction knowledge to understand, for instance, why protection diodes may be used; transistor knowledge to ensure that the device operates in the appropriate region for faithful amplification; and amplifier circuit knowledge to determine suitable resistor values, set the Q-point, design coupling networks and anticipate the frequency response.

During project work, students encounter issues that are rarely addressed in purely theoretical instruction, such as noise, distortion due to clipping or saturation, parameter variation between nominally identical components and sensitivity to power supply fluctuations. Confronting and troubleshooting these issues helps students partially shift from a physicist's mindset that seeks idealised behaviour towards an engineer's mindset that aims to achieve robust performance under constraints. In light of the examination data, the improved analog subscores and higher pass rates in the experimental cohorts suggest that this experiential dimension reinforced rather than undermined formal understanding.

5.4 Cohort Differences and Iterative Refinement

The comparison between the 2021 and 2022 experimental cohorts offers additional insights. While both cohorts outperformed the 2020 control group, the 2022 classes showed higher mean analog subscores and higher analog pass rates than the 2021 classes. This pattern is consistent with the idea that curriculum reforms and project-based components typically require iterative refinement. Over time, the instructor can better calibrate the pacing of the concentrated module, optimise scaffolding and checkpoints, and anticipate common student difficulties. Students in later cohorts may also benefit from more polished project descriptions, improved assessment rubrics and a larger pool of example circuits and troubleshooting cases.

5.5 Implications

Overall, the findings suggest that for non-electrical physics majors, a concentrated analog electronics module organised along a physically meaningful trajectory and enriched by a substantial project can foster deeper and more coherent understanding than a fragmented, calculation-oriented approach. Beyond the specific context of this course, the study illustrates how aligning the starting point of instruction with students' disciplinary strengths, and then carefully guiding them from fundamental principles to functional systems, can be an effective strategy in service courses at the interface between physics and engineering. These findings are consistent with prior reports that PBL can enhance motivation and integration of knowledge in electronics education, but they extend the literature by showing that, when combined with a carefully sequenced conceptual trajectory, PBL can be effective even for non-engineering physics majors in a service-course context.

6　CONCLUSION AND LIMITATIONS

This study examined a three-year teaching reform in a service course on *Fundamentals of Electrical and Electronic Technology* for non-engineering physics majors. By reorganising the analog electronics content into a concentrated module built around a coherent trajectory from PN junction to transistor to amplifier, and by embedding a substantial PBL project, the reform aimed to align instruction with students' physics strengths while fostering more engineering-oriented ways of thinking.

Using a quasi-experimental design with three cohorts (N = 353), the study found that students in the experimental

cohorts achieved higher overall exam scores and markedly better performance on analog electronics items than students in the traditional cohort. Pass rates improved both at the course level and for the analog subsection of the exam. These results suggest that conceptually coherent, project-rich instruction can effectively support non-engineering physics majors in developing a deeper and more integrated understanding of analog electronics.

The study has several limitations. It was conducted at a single institution within one programme, which may limit the generalisability of the findings. The quasi-experimental design relied primarily on existing exam data; more rigorous experimental controls and the use of validated concept inventories would strengthen future research. In addition, although project artefacts and brief feedback were collected, the study did not systematically analyse students' group discussions or track long-term retention of analog electronics concepts.

Despite these limitations, the findings offer practical guidance for instructors and curriculum designers responsible for service electronics courses. Organising content around a physically meaningful conceptual backbone, allocating a concentrated block of time to preserve continuity, and designing a non-trivial project that forces students to integrate device physics with circuit design appear to be promising principles. Future work could extend this approach to topics such as operational amplifiers and signal conditioning, and explore how similar reforms might support students in other non-electrical programmes and institutional contexts.

COMPETING INTERESTS

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REFERENCES

[1] Wang P, Bailey J M, Wang X. Conceptual challenges with diodes and transistors: A large-scale investigation. Physical Review Physics Education Research, 2022, 18(2): 020132. DOI: 10.1103/PhysRevPhysEducRes.18.020132.
[2] Kuo Y C, Tseng C H. Linking energy-band diagrams to circuit behaviour: A diagnostic study of physics majors. European Journal of Physics, 2023, 44(3): 035703. DOI: 10.1088/1361-6404/acc4c5.
[3] Liang J, Ma S, Zhang H. Students' use of formulas without conceptual grounding in introductory electronics. International Journal of Science Education, 2021, 43(14): 2296-2314. DOI: 10.1080/09500693.2021.1959941.
[4] Chen Y, Lin C, Wu Y. Meta-analysis of project-based learning in engineering education: 2018-2023. Journal of Engineering Education, 2024, 113(1): 1-22. DOI: 10.1002/jee.20501.
[5] Rodríguez-García A, Aznar M, Poveda P. Scaffolding strategies in analog-electronics PBL: A systematic review. European Journal of Engineering Education, 2023, 48(5): 657-675. DOI: 10.1080/03043797.2023.2187654.
[6] Zhang Q, Wang L, Yang Q. Effects of project-based learning on STEM students' motivation: An updated meta-analysis 2019-2023. International Journal of STEM Education, 2023, 10: 22. DOI: 10.1186/s40594-023-00412-0.
[7] Anderson K, Björklund A. Service electronics for scientists: Design principles and outcomes. IEEE Transactions on Education, 2022, 65(4): 301-308. DOI: 10.1109/TE.2022.3167345.
[8] Sánchez-Martín J, Alcober E, Estepa A. A threshold concept map for analog electronics: From PN junction to amplifier. Education and Information Technologies, 2024, 29: 2341-2360. DOI:10.1007/s10639-023-11998-z.
[9] Alves G, Leite L, Morgado J. Inductive teaching in large electronics classes: A quasi-experimental study. European Journal of Engineering Education, 2021, 46(6): 931-948. DOI:10.1080/03043797.2021.1889493.
[10] Al-Zoubi A, Al-Rawahneh M. Short-burst vs distributed PBL in analog electronics: A randomized crossover trial. International Journal of Electrical Engineering Education, 2024, in press. DOI: 10.1177/0020720924123456.
[11] Alharbi H, Hattab H, Alshaya A. Adaptation of PBL for non-EE majors: Physics students designing audio amplifiers. IEEE Access, 2023, 11: 87654-87667. DOI: 10.1109/ACCESS.2023.3309876.
[12] Alves A, Ferreira M. Operating-region misconceptions in BJT amplifiers: A post-pandemic snapshot. Physical Review Physics Education Research, 2022, 18(1): 010126. DOI: 10.1103/PhysRevPhysEducRes.18.010126.
[13] Al-Qahtani F, Al-Thibiti M. I-V curves as a reasoning tool for transistor biasing: An intervention study. Physics Education, 2021, 56(4): 045013. DOI: 10.1088/1361-6552/abf5d2.
[14] Delgado A, Cruz L. From band diagrams to circuit symbols: A visual bridge for physics majors. European Journal of Physics, 2024, 45(2): 025702. DOI: 10.1088/1361-6404/ad1c4f.
[15] Alshaya A, Alharbi H. Long-term retention after concentrated PBL in analog electronics: A two-year follow-up. Journal of Engineering Education, 2024, 113(3): 456-473. DOI: 10.1002/jee.20534.

CLASSROOM VIDEO BEHAVIOUR PROPOSAL MODEL BASED ON MULTIMODAL ATTENTION MECHANISMS AND ADAPTIVE SEARCH

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Abstract: The analysis of teacher-student behaviour within classroom settings forms the bedrock of smart education research and application. However, existing general-purpose behaviour detection models often exhibit suboptimal accuracy and efficiency when processing extended classroom videos. This stems primarily from their inability to effectively address four key challenges: variable behaviour duration, complex semantic layers, heterogeneous multimodal information, and high background redundancy. To address these challenges, this paper proposes a novel classroom video behaviour proposal model. Its core innovation lies in the synergistic utilisation of multimodal attention mechanisms and adaptive search strategies. First, a robust multimodal feature extraction backbone network is constructed to extract highly discriminative features from video, audio, and automatic speech recognition (ASR) transcribed text. Subsequently, a hierarchical multimodal attention fusion module is designed. This module dynamically captures and integrates behaviour-related key visual segments, audio events, and semantic keywords through two-stage computations: intra-modal attention and cross-modal attention. Building upon this foundation, we innovatively propose an adaptive boundary search algorithm inspired by reinforcement learning principles. This algorithm dynamically adjusts search stride and direction based on the contextual semantics and behavioural confidence of the current video segment, enabling efficient and precise boundary localisation for action proposals within lengthy video sequences. To validate model performance, we constructed a large-scale classroom behaviour dataset, 'Edu-Action'. Comprehensive experimental results demonstrate that our model achieves significant improvements in the core evaluation metric for action proposal tasks, average recall at action number (AR@AN). At a tIoU threshold of 0.5, recall reaches 68.7%, comprehensively outperforming multiple advanced baseline models. Extensive ablation studies further validate the effectiveness and necessity of each component within the model. This paper presents an effective solution for fine-grained action localisation in long-duration video environments, holding significant theoretical implications and broad practical application prospects.
Keywords: Behavioural proposal generation; Multimodal learning; Attention mechanisms; Adaptive search; Classroom video analysis; Smart education; Deep learning

1 INTRODUCTION

The intrinsic demand for enhancing quality and efficiency within the context of educational informatisation has made the digital and intelligent analysis of classroom teaching processes a research hotspot in the field of education [1]. The vast volume of classroom video recordings generated and stored constitutes a valuable educational big data goldmine. Automatically identifying, locating, and understanding teaching behaviours such as 'teacher board writing', 'student raising hands to speak', and 'group collaborative inquiry' holds revolutionary significance for achieving objective classroom teaching evaluation, precise teaching reflection, personalised learning situation analysis, and deep mining of educational big data [2,3]. Time-based behaviour proposals serve as the bridge connecting low-level video features with high-level behavioural understanding, representing the primary and critical component within the behavioural analysis pipeline [4]. The task objective is to precisely locate all potential start and end timepoints for behaviours of interest within an unedited, uncropped video sequence, without pre-assigned behavioural category labels, and to generate confidence scores for these locations [5]. However, the unique characteristics of classroom settings render this task exceptionally complex.

Firstly, the extreme variability in behavioural duration, with classroom actions exhibiting an exceptionally broad distribution range [6]. Instantaneous, atomic behaviours such as 'a pupil raising their hand' or 'a teacher pointing at the screen' may last merely 1 or 2 seconds [7]. Conversely, complex, high-level teaching activities like 'group project collaboration' or 'classroom debates' may persist for several minutes or even an entire lesson. This vast scale disparity poses a formidable challenge to a model's multiscale perception capabilities. Secondly, the hierarchical and nested nature of behavioural semantics. Classroom activities do not exist in isolation but form a complex hierarchical structure [8]. For instance, a macro-level behaviour like 'teacher explaining a new concept' may internally embed multiple

micro-behaviours such as 'teacher writing on the board,' 'teacher posing questions,' or 'playing instructional videos.' This phenomenon of 'behaviours within behaviours' makes it exceedingly difficult to clearly and accurately delineate behavioural boundaries. Thirdly, the strong multimodal dependency of behavioural identification. Defining classroom behaviours often cannot rely solely on visual information. Auditory cues—including shifts in the teacher's intonation, students' choral responses, sudden quietness—and linguistic information—such as specific phrasing in teacher questions or core conceptual terms mentioned during explanations—are crucial clues for identifying behavioural onset and transitions [9]. For instance, the initiation of a 'teacher posing a question' behaviour may be jointly signalled by visual cues such as a 'teacher's pause', auditory cues like an 'upward inflection in tone', and textual cues such as the presence of 'interrogative words'. Effectively aligning and integrating these heterogeneous modal information streams represents a core challenge. Fourthly, the high redundancy and intra-class variability within video backgrounds. Extensive segments unrelated to target behaviours exist within lengthy classroom videos, such as student self-study periods, classroom silences, and camera transitions [10]. Traditional sliding window or dense anchor methods generate numerous invalid proposals in these regions, resulting in substantial computational resource wastage and reduced recall rates. Concurrently, the visual and auditory manifestations of the same behaviour may exhibit significant variations across different classes and subjects, demanding robust generalisation capabilities from the model.

Existing behavioural proposal methods, such as the anchor-based SSN[11] and boundary-matching BMN[12], have achieved success on general datasets. However, their original design did not sufficiently account for the aforementioned particularities of classroom scenarios. Most rely on a single visual modality or perform simple post-fusion of multimodal information, failing to fully exploit the deep interconnections between modalities. Furthermore, they commonly employ predefined, fixed-scale anchors or sliding windows, rendering them ill-suited to accommodate the extreme temporal variability inherent in classroom behaviours. This limitation creates bottlenecks in both accuracy and efficiency. To address these issues, this paper proposes an end-to-end classroom behaviour proposal model. Its core contribution lies in designing a hierarchical multimodal attention fusion module that dynamically and efficiently integrates visual, auditory, and linguistic information while focusing on behaviour-relevant key cues. Concurrently, an adaptive boundary search algorithm is introduced. By simulating human browsing and focusing behaviours, it dynamically adjusts search strategies, significantly enhancing efficiency in long-video analysis while maintaining recall rates. Notably, a large-scale, high-quality classroom behaviour dataset, 'Edu-Action', has been constructed to advance research in this domain.

2 RELATED RESEARCH

2.1 Generation of Timed Behaviour Proposals

Time-based action proposal generation constitutes a foundational task within video understanding, with its specific architecture illustrated in Figure 1. Early approaches such as S-CNN[13] and SST[14] primarily relied on sliding windows of varying scales across video sequences to generate candidate segments, a method characterised by high computational demands and limited flexibility. Subsequently, the BMN model, based on boundary matching principles, achieved high-quality proposal generation by evaluating all candidate intervals between start-end point pairs, becoming a landmark work in the field. Later efforts such as DBG[15] and RTD-Net[16] further optimised the precision of boundary localisation. However, these approaches were primarily designed for short video clips or sports events. Their fixed anchor scales or matching mechanisms often prove inadequate when confronted with behaviours spanning vast durations within lengthy classroom videos. Moreover, the substantial volume of negative sample proposals they generate severely impacts training efficiency and final performance.

Video Frames Sequence (Teacher Question-Student Answer)

Frame 1	Frame 2	Frame 3	Frame 4	Frame 5	Frame 6	Frame 7	Frame 8	Frame 9	Frame 10
Teacher Prepares	Teacher Starts	Teacher Asking	Waiting for Answer	Student Starts	Student Answering	Student Continues	Student Finishes	Teacher Responds	Continues Teaching
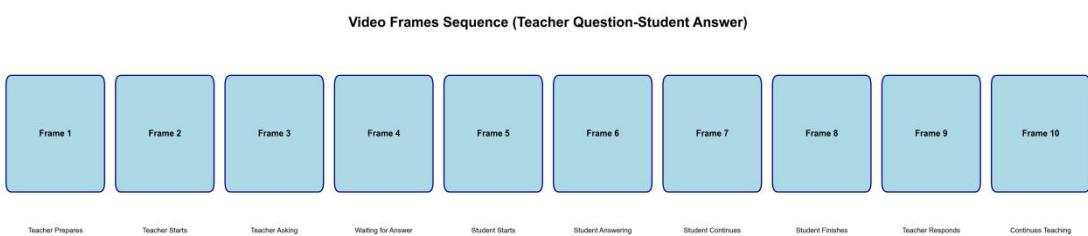
Figure 1 Temporal Behavior Proposal Generation Structure

2.2 Multimodal Video Understanding

Video is inherently a natural amalgamation of visual, auditory, and textual information. Effectively integrating these heterogeneous modalities constitutes the core challenge of multimodal learning [17]. Early fusion approaches included simple feature concatenation, max/mean pooling, and similar techniques. Subsequently, tensor-based fusion methods and bilinear pooling were proposed to capture more complex interactions between modalities, though these often entailed substantial computational overhead [18]. In recent years, attention mechanisms—particularly self-attention within Transformer architectures and cross-modal attention—have become mainstream techniques for multimodal fusion [19]. These enable models to dynamically compute importance weights across different modalities and within the

same modality at distinct temporal steps. In classroom settings, Sameer et al. attempted to utilise audio event detection to augment behaviour recognition, yet failed to achieve end-to-end deep fusion [20]. Our work draws inspiration from this approach but introduces a more refined hierarchical attention structure designed to capture cross-modal temporal alignment relationships in classroom behaviours with greater precision.

2.3 Efficient Video Analysis and Search Strategies

To address the inefficiency of long video analysis, researchers have proposed various strategies. Some approaches employ a two-stage strategy, involving coarse screening followed by fine-tuning. Others attempt to learn search strategies through reinforcement learning, intelligently skipping irrelevant frames. In recent years, the state space model Mamba has garnered attention for its efficiency in modelling long sequences [21]. Our adaptive search module shares the underlying philosophy with such approaches, but innovatively links the search stride directly to the local contextual information and behavioural confidence of the current segment. This achieves a data-driven, content-aware dynamic search mechanism better suited to the uneven distribution of classroom behaviours.

3   METHODS

In the method proposed in this study, we construct an end-to-end framework whose core process commences with deep feature extraction from visual, audio, and transcribed textual components of classroom videos. Subsequently, through a hierarchical multimodal attention module, it dynamically calculates intra-modal and cross-modal attention weights to adaptively fuse the most semantically relevant visual segments, audio events, and textual keywords associated with behavioural semantics. This ultimately drives an innovative adaptive search algorithm. This algorithm intelligently adjusts the search stride and direction based on the contextual semantics and behavioural confidence of the current segment. Consequently, it efficiently and accurately locates the start and end boundaries of potential behavioural segments within lengthy video sequences. The specific architecture is illustrated in Figure 2. The overall architecture comprises three core components: multimodal feature extraction, a hierarchical multimodal attention fusion module, and an adaptive proposal search module.
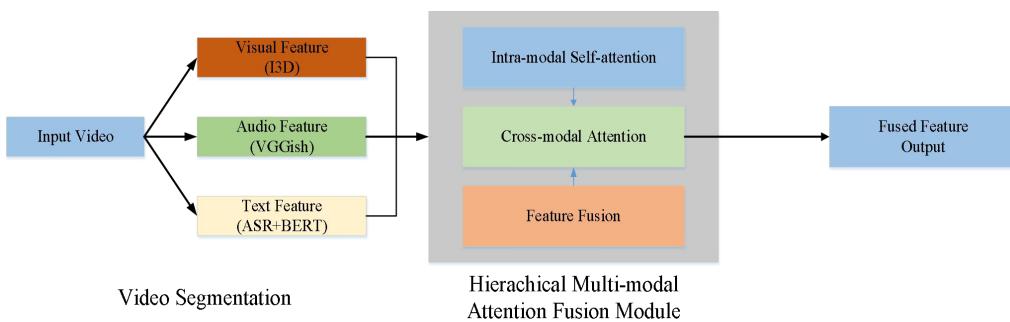
Figure 2 Model Architecture Diagram

3.1 Multimodal Feature Extraction

As illustrated in Figure 1, given a long classroom video clip V, we first uniformly partition it into non-overlapping segments of length L. For each segment t, we concurrently extract features from three modalities, as detailed in Figure 3.
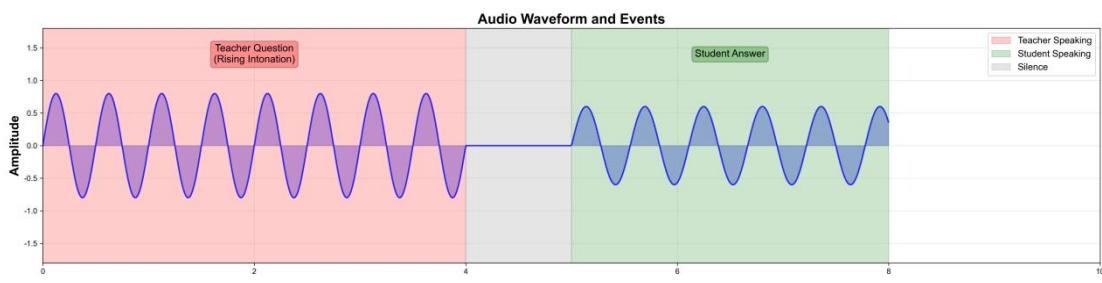
Figure 3 Multimodal Features

Visual features $F_t^v \in R^{d_v}$. To capture appearance and motion information, we employ the I3D model pre-trained on the large-scale action recognition dataset Kinetics-400 [22] as the backbone network [23]. For each clip, we extract its RGB frames and corresponding optical flow frames, pass them through the I3D network respectively, and concatenate the features obtained before the final fully-connected layer to yield the final visual feature vector F_t^v.

Audio features $F_t^a \in R^{d_a}$. We employ the VGGish model to extract audio features [24]. This model, pre-trained on a large-scale YouTube audio dataset, captures semantic information of meaningful audio events. We extract the log-Mel spectrogram from the audio waveform aligned with the video clip and feed it into the VGGish network to obtain F_t^a.

Text features $F_t^t \in R^{d_t}$. We first utilise industrial-grade automatic speech recognition (ASR) services (such as Google Cloud Speech-to-Text[25] or Azure Speech Services[26]) to convert the audio stream into a timestamped text transcription. Subsequently, for each video segment t, we aggregate all corresponding transcribed text sentences within its temporal scope. Finally, sentence embedding vectors for this aggregated text are obtained using a pre-trained BERT model[27] as text feature Ftt. This feature encapsulates rich semantic information, such as keywords and interrogative sentences.

Ultimately, we obtained three feature sequences,

$$F^v = \left\{ F_1^v, F_2^v, ..., F_L^v \right\}, F^a = \left\{ F_1^a, F_2^a, ..., F_L^a \right\}, F^t = \left\{ F_1^t, F_2^t, ..., F_L^t \right\} \circ$$

3.2 Hierarchical Multi-modal Attention Fusion Module

This module is designed to dynamically and selectively fuse information from three modalities, amplifying behaviour-relevant cues while suppressing irrelevant noise. Its architecture, as depicted in Figure 4, comprises two hierarchical levels.

First, we apply a Transformer encoder layer [28] to the feature sequences of each modality, performing intra-modal self-attention calculations. Taking the visual modality as an example, this is illustrated in Equation 1.

$$\breve{F}^v = Transformer(F^v) \tag{1}$$
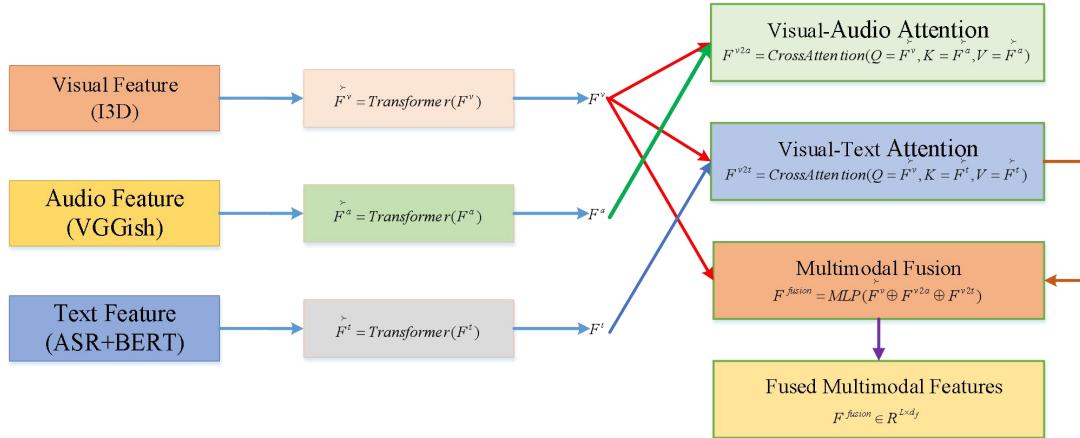
Figure 4 Hierarchical Multi-modal Attention Fusion Module

Here, $\breve{F}^v$ denotes the sequence of visual features enhanced through modal self-attention. The self-attention mechanism captures long-range temporal dependencies. For instance, it enables the model to recognise that an action such as 'a pupil standing up' may correlate with an action like 'a teacher posing a question' several seconds prior, even when intervening frames are unrelated. Similarly, the enhanced audio features $\breve{F}^a$ and text features $\breve{F}^t$ are obtained as shown in Equations 2 and 3.

$$\breve{F}^a = Transformer(F^a) \tag{2}$$

$$\breve{F}^t = Transformer(F^t) \tag{3}$$

Following the extraction of enhanced features across modalities, cross-modal information interaction and fusion are performed. A vision-dominant fusion strategy is adopted, as vision serves as the primary vehicle for behavioural expression. Specifically, visual features are employed as the Query, with audio and text features functioning as Key and Value respectively, to conduct cross-attention computations.

Visual and audio fusion enables the model to recalibrate the importance of visual features using audio cues, such as sudden applause or loud questions, as illustrated in Equation 4. When audio features indicate 'applause,' the model prioritises segments showing 'students standing' or 'teachers gesturing' in the visual data.

$$F^{v2a} = CrossAttention(Q = \breve{F}^v, K = \breve{F}^a, V = \breve{F}^a) \tag{4}$$

The fusion of visual and textual information enables semantic cues to guide the allocation of visual attention, as illustrated in Equation 5. For instance, when the text prompts 'Let's discuss this in groups,' the model will purposefully seek visual patterns such as 'students turning their heads' or 'forming groups' within the corresponding visual segments.

$$F^{v2t} = CrossAttention(Q = \breve{F}^{v}, K = \breve{F}^{t}, V = \breve{F}^{t}) \tag{5}$$

Finally, we fuse the original enhanced visual features with the two cross-modal attention outputs, as shown in Equation 6.

$$F^{fusion} = MLP(\breve{F}^{v} \oplus F^{v2a} \oplus F^{v2t}) \tag{6}$$

Here, $\oplus$ denotes the vector concatenation operation, while MLP represents a multi-layer perceptron used to project the concatenated high-dimensional features onto a unified fusion feature space $F^{fusion} \in R^{L \times d_f}$.

3.3 Adaptive Proposal Search Module

Traditional dense generation-evaluation strategies prove inefficient for long-form videos. Inspired by human viewing behaviour—specifically the cycle of "skimming through—identifying points of interest—pausing to examine in detail"—we have designed an adaptive proposal search module. This module operates iteratively, with its core principle being the dynamic determination of the "direction" and "step size" for the next search step based on the context surrounding the current search position. As illustrated in Figure 5, the adaptive proposal search process emulates intelligent human browsing behaviour during long-form video consumption. It abandons the traditional sliding window strategy with fixed strides, instead dynamically adjusting search granularity and direction based on contextual semantic information from the current video segment and predicted behavioural confidence. When the search pointer resides in behaviourally sparse regions, the algorithm employs larger strides to rapidly skip irrelevant segments, enhancing efficiency. Conversely, upon detecting regions of high behavioural confidence, it automatically switches to a fine-grained small-step search mode. Within these zones, it densely generates proposals and performs boundary fine-tuning. This achieves an optimal balance between efficiency and precision within lengthy lecture videos, avoiding computational waste on irrelevant background content while ensuring the capture of fleeting or marginally defined behavioural patterns.
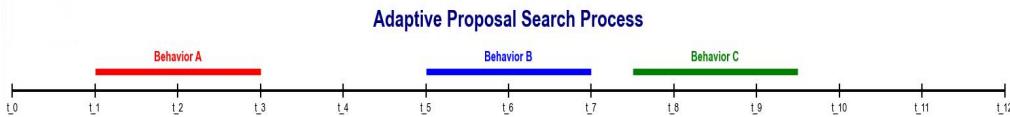
Figure 5 Adaptive Proposal Search Process

In each iteration i , the model maintains a current search pointer p_i and observes a local context window C_i centred on a feature p_i . The window's features F^{fusion} are encoded by a small neural network g_{ctx} applied to the corresponding fragments from the fused features, as shown in Equation 7.

$$s_i = g_{ctx}(C_i) \tag{7}$$

Here, s_i denotes the current state representation.

4   EXPERIMENTS AND DISCUSSION

4.1 Experimental Setup

Regarding dataset design, as existing public datasets (such as ActivityNet and THUMOS) are unsuitable for classroom scenarios, we have developed our own 'Edu-Action' dataset. This dataset comprises 500 hours of authentic classroom videos spanning different educational stages (primary, secondary, and sixth form) and subjects (Chinese, mathematics, English, etc.). A team of educational experts was engaged to annotate over 20,000 time intervals according to rigorous standards. These annotations encompass ten core teaching behaviours: 'teacher instruction', 'board writing', "questioning", 'individual student responses', 'collective student responses', 'group discussions', 'individual practice', 'teacher-student interaction', and 'student-student interaction'.

Regarding evaluation metrics, we employ the most prevalent assessment protocol within the behavioural proposal domain: average recall across different IoU thresholds. We report average recall at the tIoU threshold set {0.5, 0.55, ..., 0.95}, calculating AR@50 and AR@100 for average proposal counts of 50 and 100 respectively. Additionally, we output the AUC, representing the area under the recall curve across the tIoU threshold range [0.5:0.05:0.95].

In terms of implementation details, the video is downsampled to 5 frames per second. I3D, VGGish, and BERT all utilise pre-trained weights which are fixed, with only the subsequent fusion network being fine-tuned. The Adam optimiser is employed, with an initial learning rate of 1e-4. Training of the APS module adopts curriculum learning, commencing with simpler videos.

4.2 Experimental Comparison

In terms of experimental comparisons, we contrast our approach with several state-of-the-art generalised action proposal methods, including SSN, BMN, MGG, and RTD-Net. To ensure fair evaluation, all baseline methods were retrained on the Edu-Action dataset using the identical multimodal features provided by us, as detailed in Table 1.

Table 1 Performance Comparison of Behavioural Proposals on the Edu-Action Test Set

Mehtod	Modal	AUC	@0.5	@0.7	@0.9
SSN[11]	RGB	28.1	42.5	28.9	8.1
BMN[12]	RGB	32.5	52.1	36.8	12.5
MGG[29]	RGB	33.8	54.3	38.1	13.2
RTD-Net[16]	RGB	35.2	56.7	40.5	14.8
BMN[12]	RGB+Audio	34.9	55.8	39.4	13.7
BMN[12]	RGB+Audio+Text	36.1	57.5	41.0	14.5
Ours	RGB+Audio+Text	41.7	68.7	53.4	21.2

The experimental results demonstrate that our approach achieves significant and consistent superiority over all baseline models across all evaluation metrics. Particularly under stringent metrics measuring boundary localisation accuracy, it achieves absolute performance gains of 12.0% and 12.9% respectively compared to the strongest baseline, RTD-Net. This conclusively demonstrates our model's distinct advantage in generating precise, high-quality boundary proposals. It is noteworthy that while incorporating multimodal information into baseline methods yields some performance gains, these improvements remain limited. This indicates that simple feature concatenation strategies struggle to fully exploit the deep correlations between multimodal information. In contrast, the hierarchical attention mechanism proposed herein achieves more effective fusion through dynamic weight allocation. Furthermore, our approach maintains a recall rate exceeding 21%, whereas all baseline methods fall below 15%. This outcome robustly validates our model's exceptional precision in behavioural boundary localisation, demonstrating superior alignment with actual behavioural intervals.

4.3 Ablation Experiment

The ablation experiments aim to systematically validate the effectiveness of each core component within the model, following the implementation process outlined below. First, building upon the complete model, we sequentially removed or substituted specific modules. This included: - Isolating audio and text modalities to validate multimodal necessity. Replacing hierarchical attention with simple feature concatenation to assess fusion efficacy. Ablating intra-modal and cross-modal attention submodules to analyse their respective contributions. Substituting adaptive search strategies with traditional fixed-step sliding windows to evaluate efficiency advantages. All comparative experiments were conducted under identical training/validation/test dataset partitions, employing consistent hyperparameter settings and evaluation metrics to ensure comparability. This approach precisely quantifies each component's contribution to final performance. Specific results are presented in Table 2.

Table 2 Ablation Experiment Results

Model Configuration	AUC	@0.5	@0.7
Complete Model	41.7	68.7	53.4
- w/o Audio modal	38.9	64.1	48.5
- w/o Text modal	39.5	65.0	49.3
- w/o HMAF	37.2	61.5	45.7
- w/o Modal attention	40.1	66.3	51.0
- w/o Cross-modal attention	40.5	66.8	51.5
- w/o APS	35.9	59.8	43.6

Regarding the necessity of multimodality, removing either the audio or text modality resulted in a significant decline in performance, decreasing the AUC by 2.8 and 2.2 points respectively. This demonstrates the indispensable role of multimodal information in classroom behaviour analysis. Regarding the efficacy of the HMAF module [30], performance plummeted when this module was replaced with simple feature concatenation, with AUC dropping from 41.7 to 37.2. This demonstrates the critical role of our proposed attention mechanism in information fusion. Furthermore, removing either the intra-modal or cross-modal attention submodules separately also resulted in performance degradation, indicating both are effective, with intra-modal attention playing a slightly greater role than cross-modal attention. Regarding the effectiveness of the APS module, replacing it with a traditional fixed-step sliding window yielded the most pronounced performance decline, with AUC dropping to 35.9, demonstrating the substantial advantages of adaptive search strategies in enhancing both accuracy and efficiency. We also measured inference time, where the full model achieved approximately 3.5 times faster processing compared to the sliding-window variant.
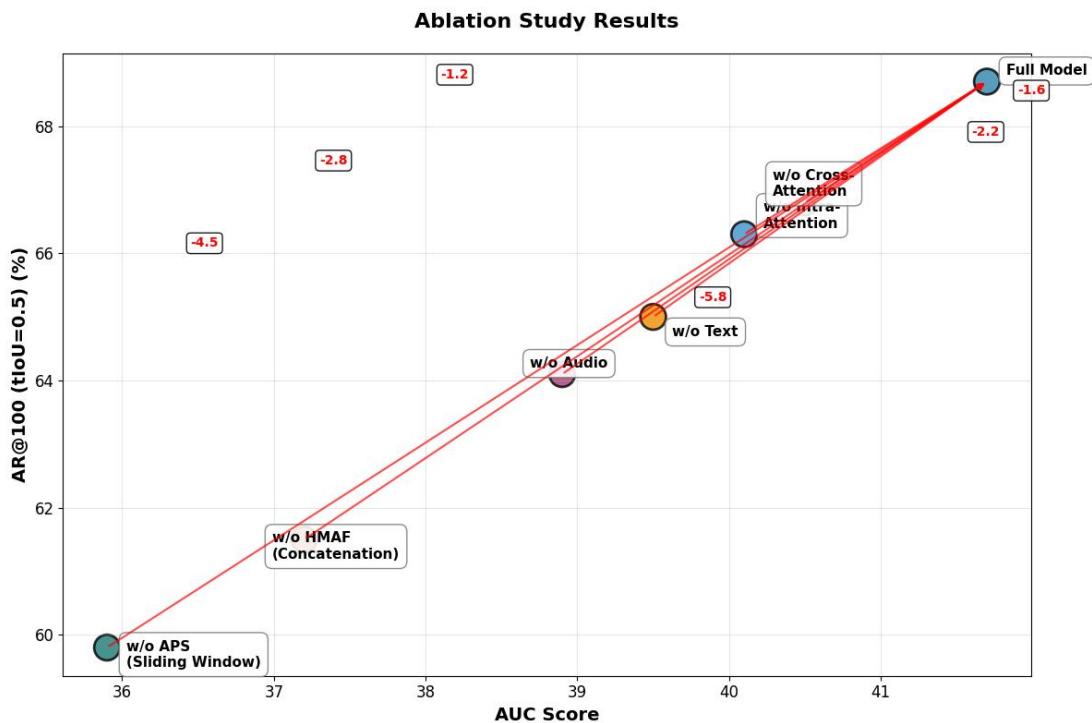
Figure 6 Scatter Plot of Performance Metrics for Each Model Configuration in Ablation Experiments

As illustrated in Figure 6, the performance scatter plot from the ablation experiments clearly reveals the contribution of each component to model performance and their intrinsic relationships. The complete model occupies the optimal position with 68.7% AR@0.5 and 41.7% AUC, demonstrating the best overall performance. When the adaptive search strategy was removed in favour of a traditional sliding window approach, performance declined most markedly, AR@0.5 decreased to 59.8% and AUC fell to 35.9%, confirming the critical role of adaptive search in enhancing detection efficiency and boundary accuracy. Replacing the hierarchical attention mechanism with simple feature concatenation caused AR@0.5 drop in a to 61.5% and AUC to 37.2%, highlighting the necessity of refined multimodal fusion. Removing either the audio or text modality individually caused varying degrees of performance degradation, confirming the complementary value of multimodal information. The greater impact observed when the audio modality was absent indicates that audio cues are particularly crucial for behaviour recognition in classroom settings. Notably, performance degradation from removing intra-modal attention slightly exceeded that from cross-modal attention removal, indicating that capturing intra-modal temporal dependencies contributes more significantly to final performance than cross-modal alignment. These results collectively demonstrate that the model's components synergistically enhance behaviour detection performance, with adaptive search strategies making the greatest contribution, followed by hierarchical attention mechanisms, while multimodal information provides indispensable complementary cues.

4.4 Discussion of Results

We conducted a case study to visualise the temporal attention weights of successful examples, as illustrated in Figure 7. The figure depicts the visualisation of attention weights during a "teacher-question-student-answer" process. The top section displays video frames, the middle shows audio waveforms and transcribed text, while the bottom presents tri-modal attention weights. It is evident that at the start of the question, textual attention focuses on the word 'why', while audio attention concentrates on the rising intonation. During the student's response, visual attention centres on the student's area, audio attention shifts to the student's voice, and textual attention aligns with the content of the student's answer. Our model successfully localises the entire interaction process.
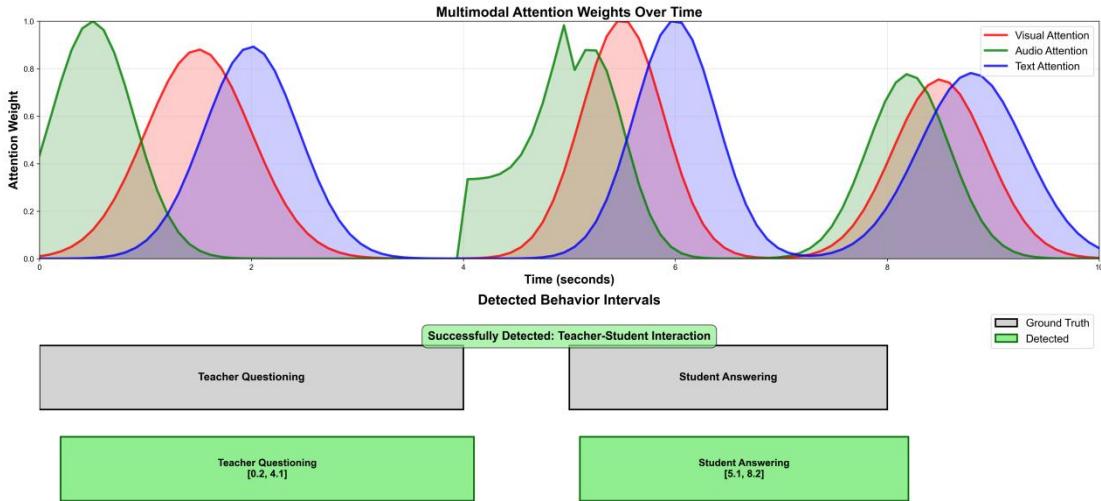
Figure 7 Visualisation of Temporal Attention Weights

Moreover, we have also observed instances of failure. Firstly, extremely ambiguous boundaries, such as a group discussion that commences slowly without clear linguistic markers. Additionally, multimodal signals of extremely poor quality, such as severe camera shake, audio containing significant noise, or entirely erroneous ASR transcriptions. These too represent challenges that require continued attention in future work.
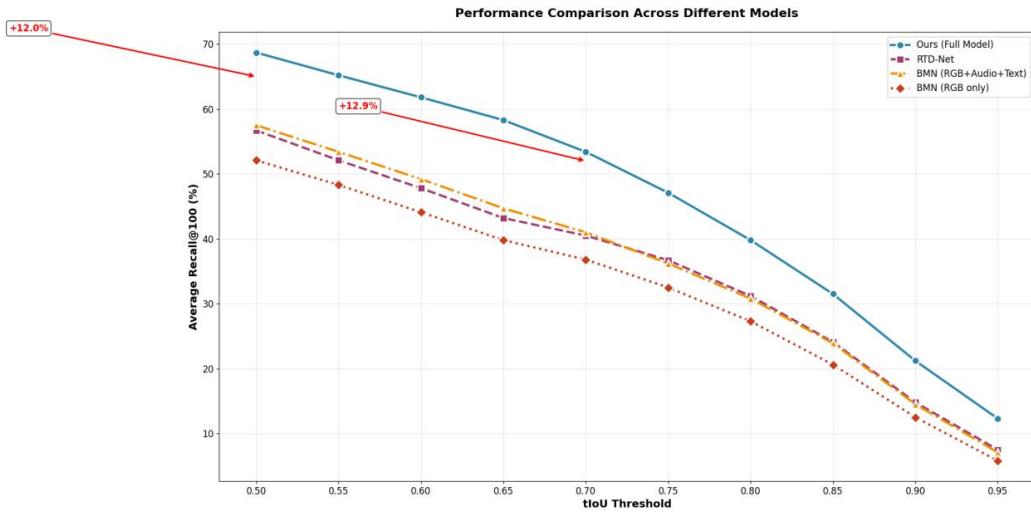
Figure 8 Performance Curves of Different Models at Various tIoU Thresholds

For the comparative experiments conducted in this paper, we performed a performance analysis, as detailed in Figure 8. The figure illustrates the average recall trends across different models as the tIoU threshold varies from 0.5 to 0.9. Our proposed model maintains a leading position across all thresholds, exhibiting the most gradual decline in performance curves. This indicates that the generated behavioural proposals demonstrate superior boundary accuracy and robustness. Specifically, under stringent thresholds tIoU@0.5 and @0.7, our model achieves absolute performance improvements of 12.0% and 12.9% respectively compared to the strongest baseline RTD-Net, highlighting its significant advantage in precisely locating behavioural boundaries. Even as the threshold increases to @0.9, the proposed model maintains a recall rate of 21.2%, substantially exceeding the baseline model's rate below 15%, further validating its capability to capture extreme precision boundaries. This outcome stems from the hierarchical attention mechanism's dynamic fusion of multimodal information, effectively leveraging complementary visual, auditory, and textual cues. Concurrently, the adaptive search strategy intelligently adjusts granularity within lengthy videos, mitigating background redundancy while enhancing detection of critical behavioural regions. This holistic approach elevates the model's performance across varying levels of strictness.

5 CONCLUSION

This paper addressed the core challenges in temporal action proposal generation for classroom videos, namely the extreme variation in action durations, complex semantic hierarchies, and the heterogeneous nature of multimodal information. We proposed a novel proposal generation model centered on a Hierarchical Multimodal Attention Fusion

(HMAF) module and an Adaptive Proposal Search (APS) strategy. Comprehensive experiments and in-depth analysis on the collected Edu-Action dataset lead to the following principal conclusions.

First, the proposed HMAF module and APS algorithm are conclusively identified as the key drivers for the performance superiority of our framework. The significant performance gains, evidenced by absolute improvements of 12.0% and 12.9% in AR@100 at tIoU thresholds of 0.5 and 0.7, respectively, over the strongest baseline RTD-Net, demonstrate a substantial advancement in generating high-quality proposals with precise temporal boundaries. The model's robustness is further highlighted by its maintained recall of over 21% at the highly stringent tIoU threshold of 0.9, significantly surpassing all baseline methods and underscoring its exceptional capability in localizing actions with ambiguous boundaries or short durations.

Second, the results of the ablative studies, clearly visualized via a performance scatter plot, quantitatively dissect the contribution of each component. The Adaptive Proposal Search mechanism is confirmed to be the most critical innovation, as its replacement with a sliding window approach resulted in the most severe performance degradation. This underscores its indispensable role in achieving an optimal balance between efficiency and accuracy in long, untrimmed videos. The Hierarchical Multimodal Attention Fusion module is the second most significant contributor. Its performance gain far exceeded that of a simple feature concatenation baseline, validating the effectiveness of its dynamic, fine-grained fusion of visual, acoustic, and linguistic cues through intra- and cross-modal attention for deep semantic alignment and enhancement. Furthermore, the performance drop observed from removing either the audio or text modality confirms the necessity of multimodal information, with the slightly larger impact from ablating audio suggesting the particularly strong discriminative power of vocal and acoustic events in the classroom context.

In summary, this work not only delivers a model that significantly outperforms the state-of-the-art for classroom behavior analysis but also, through meticulous experimentation, elucidates the critical roles and underlying mechanisms of sophisticated multimodal fusion and intelligent search strategies for fine-grained action localization in long videos. It provides a reliable tool for automated classroom behavior analysis in the domain of smart education and offers a valuable framework and insights for the broader field of long-form, multimodal video understanding.

Future work will focus on model lightweighting for practical deployment, enabling online real-time processing, and enhancing cross-scenario generalization to foster application in real-world intelligent classroom environments and provide more powerful support for teaching analytics and assessment.

COMPETING INTERESTS

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REFERENCES

[1] Jain A, Dubey K A, Khan S, et al. A PSO weighted ensemble framework with SMOTE balancing for student dropout prediction in smart education systems. Scientific Reports, 2025, 15(1): 17463-17463.
[2] Chen J, Qian L, Ni H. The Smart Classroom Practices in Science Courses. Higher Education and Practice, 2024, 1(8).
[3] Yanqiu Z ,Yinghua S, Rongxia H, et al. The Development and Application of the Metaverse in Smart Education in Chinese Universities. Frontiers in Educational Research, 2024, 7(6).
[4] Xu Z, Zhou Q, Li Z, et al. Adaptive Multi-Function Radar Temporal Behavior Analysis. Remote Sensing, 2024, 16(22): 4131-4131.
[5] Andriani R, Disman, Ahman E, et al. Polychronic Behaviors: The Role of Job Residency and Education Level. International Journal of Entrepreneurship, 2019, 23(3).
[6] Petrov M. Analyzing and classifying a range of incorrect actions made by students during an educational process using an interval temporal behavior observation. Educational Alternatives, 2019, 17(1): 117-126.
[7] Sarra A, Leila J M, Fahima H, et al. Fuzzy Vikor Application for Learning Management Systems Evaluation in Higher Education. International Journal of Information and Communication Technology Education (IJICTE), 2021, 17(2): 17-35.
[8] Ukpong E D, George N I. Length of Study-Time Behaviour and Academic Achievement of Social Studies Education Students in the University of Uyo. International Education Studies, 2013, 6(3): 172.

[9] Derya S, Felix H, Magdalena B, et al. Early and middle latency auditory event-related potentials do not explain differences in neuropsychological performance between schizophrenia spectrum patients and matched healthy controls. Psychiatry Research, 2021, 304(prepublish): 114162-114169.

[10] Tucholka I, Gold B. Analysing classroom videos in teacher education— How different instructional settings promote student teachers' professional vision of classroom management. Learning and Instruction, 2025: 97102084-102084.

[11] Stapleton N J, Richardson R M. Social Support Network and Sedentary Behavior Among US Adults With and Without Mobility Impairment. American journal of health promotion: AJHP, 2024, 38(7): 8901171241252526-8901171241252526.

[12] Peng Z, Jitong W, Mengshu L, et al.Structure, electrical properties and energy storage performance of BNKT-BMN ceramics. Journal of Materials Science: Materials in Electronics, 2022(prepublish): 1-12.

[13] Ghaderi A, Athitsos V. Selective Unsupervised Feature Learning with Convolutional Neural Network (S-CNN). CoRR, 2016.

[14] Moss H E, Tantry K E, Le E, et al. Distinct patterns of PV and SST GABAergic neuronal activity in the basal forebrain during olfactory-guided behavior in mice. The Journal of neuroscience: the official journal of the Society for Neuroscience, 2025.

[15] Zeinab H Z, Shekoufeh R K, Esmaeil F, et al. Distributed RMI-DBG model: Scalable iterative de Bruijn graph algorithm for short read genome assembly problem. Expert Systems With Applications, 2023, 233.

[16] Changyou D, Hong L, Han Z, et al. New Understanding on Relationship Between RTD Curve and Inclusion Behavior in the Tundish. Metallurgical and Materials Transactions, 2024, 55(4): 2224-2239.

[17] Tu L, Hong H. Multimodal Learning Data Analysis and Algorithmic Teaching Effectiveness Evaluation Model Construction. International Journal of High Speed Electronics and Systems, 2024(prepublish).

[18] Cai Q, Bajuri R M, Leong E K, et al. Multimodal Learning Interactions Using MATLAB Technology in a Multinational Statistical Classroom. Multimodal Technologies and Interaction, 2025, 9(10): 106-106.

[19] Sun C, Huang S, Sun B, et al. Personalized learning path planning for higher education based on deep generative models and quantum machine learning: a multimodal learning analysis method integrating transformer, adversarial training and quantum state classification. Discover Artificial Intelligence, 2025, 5(1): 29-29.

[20] Gajghate S S , Noor M M, Kumar S, et al. A transformer guided multi modal learning framework for predictive and causal assessment of thermal runaway in high energy batteries. Scientific Reports, 2025, 15(1): 37054-37054.

[21] Zhang X, Bahri A, Desrosiers C, et al. SegMamba: Mamba-based Incomplete Multimodal Learning for Brain Tumor Segmentation with Few Samples. IEEE journal of biomedical and health informatics, 2025. DOI: 10.1109/JBHI.2025.3600652.

[22] Huafeng W, Hanlin L, Wanquan L, et al. Temporal information oriented motion accumulation and selection network for RGB-based action recognition.I mage and Vision Computing, 2023, 137.

[23] Ng L H D, Chia T R T, Young E B, et al. Study protocol: infectious diseases consortium (I3D) for study on integrated and innovative approaches for management of respiratory infections: respiratory infections research and outcome study (RESPIRO). BMC infectious diseases, 2024, 24(1): 123-123.

[24] Abd I E L E, Emad N S E, K K M, et al. VGGish transfer learning model for the efficient detection of payload weight of drones using Mel-spectrogram analysis. Neural Computing and Applications, 2024, 36(21): 12883-12899.

[25] Iancu B. Evaluating Google Speech-to-Text API's Performance for Romanian e-Learning Resources. Informatica Economica, 2019, 23(1): 17-25.

[26] CallMiner Combines Conversation Analytics Platform With Microsoft Azure Speech to Text. Telecomworldwire, 2021.

[27] Huang P, Zhu H, Wang Y, et al. Enhanced Semantic BERT for Named Entity Recognition in Education. Electronics, 2025, 14(19): 3951-3951.

[28] Shylaja R, Kumari R V L. ArrhythTransform: Multi-Head Attention-Based Transformer Encoder for Arrhythmia Classification. Engineering Letters, 2025, 33(11).

[29] Dixit A, Kumar S, Kumar N, et al. Assessing the impact of process and design variations on reliability of complementary FET. Solid State Electronics, 2025: 230109226-109226.

[30] Ying L, Wujie Z. Hierarchical Multimodal Adaptive Fusion (HMAF) Network for Prediction of RGB-D Saliency. Computational Intelligence and Neuroscience, 2020: 20208841681-8841681.

PRACTICAL FEATURES AND DISSEMINATION DILEMMAS OF TEACHING REFORM PROJECTS IN VOCATIONAL COLLEGES

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Abstract: Higher vocational education reform projects are characterized by distinct practical features, embodied in the fact that "projects originate from practice, are researched within practice, and their outcomes are applied back to practice." This essential attribute profoundly influences the methods, pathways, and effectiveness of outcome dissemination. Currently, the promotion of these reform outcomes faces three main dilemmas: distinct school-based characteristics leading to insufficient confidence in promotion, questioned quality affecting the perceived value of dissemination, and a lack of motivation within project teams for promotion. In response to these issues, this paper proposes optimization strategies: selecting universal teaching issues for project initiation at the source, enhancing the quality and operability of outcomes, diversifying the forms of outcomes to increase targeted applicability, and establishing multi-level communication platforms to facilitate the effective dissemination and application of reform outcomes, thereby improving the utilization efficiency of educational resources.
Keywords: Educational reform project; Practical characteristics; Achievement promotion; Dilemma

1 INTRODUCTION

Higher vocational education reform projects serve as crucial means to promote innovation in teaching and enhance the quality of talent cultivation. All higher vocational colleges attach great importance to investing in these reform projects and have yielded numerous high-quality outcomes. However, for a long time, many higher vocational colleges in China have exhibited a tendency to "emphasize project approval while neglecting promotion, and prioritize achievements over application. Consequently, numerous educational reform projects are shelved upon completion, and the results are not promptly summarized, promoted, and applied, leading to a significant waste of educational resources" [1].

Currently, there is abundant research on the challenges faced in promoting the outcomes of educational reform projects, but it primarily focuses on empirical summaries and analyses. However, there has been no in-depth exploration into the logical relationship between the essential attributes of educational reform projects and the promotion of their outcomes. Educational reform projects are characterized by the principle that "projects originate from practice, are researched in practice, and have their research outcomes applied in practice." The "practical characteristics" are the essential features of educational reform projects, which constrain the methods and forms of "outcome promotion" and influence the paths and effects of "outcome promotion." Accurately grasping the inherent logical relationship between the "practical characteristics" of educational reform projects and "outcome promotion" can effectively and deeply analyze the root causes of the challenges faced in promoting the outcomes of educational reform projects. This, in turn, can help formulate more effective promotion strategies to alleviate the difficulties encountered in outcome promotion.

2 PRACTICAL CHARACTERISTICS: THE ESSENTIAL ATTRIBUTE OF HIGHER VOCATIONAL EDUCATION REFORM PROJECTS

Higher vocational education reform projects differ from general educational and scientific research projects. They exhibit distinct practical characteristics in terms of project setup, topic sources, research processes, and application of research outcomes. "Practicality" is the essential attribute of higher vocational education reform projects.

2.1 Source of the Topic: The Project Originates from Practice

The purpose of setting up educational reform projects is to improve teaching practice. The formation of these reform projects is not based on the personal interests of researchers, nor is it aimed at constructing corresponding educational theories. Instead, it is to effectively solve problems in teaching practice. "Exploring the laws of education and teaching and constructing theories of development teaching are only derivative functions derived from teaching research practice. Their purpose lies in promoting educational reform rather than enhancing the academic quality of teaching theories" [2].

The higher vocational education reform project originates from the problems encountered in school-based practice. "Universities face various problems and contradictions in the process of talent cultivation and education teaching. These problems restrict the smooth development of teaching work in schools and affect the improvement of talent cultivation quality. If they are not dealt with and resolved in a timely manner, it will be difficult to make teaching adapt to the needs of society and individual student development, and it will be difficult to achieve the expected educational

goals"[3]. Moreover, these problems are different from routine issues in general work, as they are complex and widespread. Existing educational teaching experience is difficult to directly apply, and it is necessary to organize capable personnel through project approval, conduct in-depth research, explore reforms, and focus on solving these difficult problems in educational   teaching practice.

2.2 Research Process: Conducting Research in Practice

The research process of higher vocational education reform projects is conducted in practice, representing an action research. It exhibits distinct practical characteristics in terms of the research subject, research environment, and research process.

In terms of research subjects, the researchers are primarily frontline teachers or teaching administrators in schools. They are not observers but actual participants. This also places high demands on the participating members. Without strong educational research capabilities, they cannot directly benefit from the already overwhelming amount of scientific research achievements, nor can they scientifically analyze projects and propose reasonable action plans. Similarly, if the project team does not have strong control over the reform targets, it will be difficult to mobilize corresponding human and material resources, making it challenging to advance the reform actions.

In terms of research environment, it exhibits characteristics of authenticity and variability. On the one hand, it is conducted in a naturally authentic school teaching environment, which includes both macro-level school teaching work and micro-level daily teaching work between teachers and students. The authentic environment allows the project team to feel the complexity of practice. On the other hand, this environment will also present a state of change as research and reform progress. Researchers need to assess the impact of changes in internal and external environments in a timely manner and adjust research and action plans according to the actual situation.

In the process of research, research and reform practice mutually constrain and interact. The process of research is combined with the action process of practitioners. Research and action interact and mutually constrain each other. Scientific research results will provide strong guidance for reform, and the advancement of reform also verifies the results of research to a certain extent, while opening up new horizons for further research.

In terms of the technical route of research, the specific steps and methods for advancing educational reform projects depend on the actual context of each specific topic, and there is no unified and clear model or procedure. However, when summarized, a general thread can be found:"Planning: including the overall plan of the research and the preliminary plan for each specific action step; Action: implementing the plan according to the purpose, and the action should be flexible and dynamic, involving the understanding and decision-making of the actors; Inspection: inspecting the process, results, background, and characteristics of the actors, not rigidly adhering to specific procedures and techniques, and encouraging the use of various effective technical means and methods; Reflection: summarizing various phenomena related to the formulation and implementation of the plan that are perceived, describing the process and results of this cycle" [4].

2.3 Application of Results: Applying Results to Practice

The content, form, and application methods of the achievements of educational reform projects differ from those of typical educational research projects, exhibiting strong practical characteristics.

The application of achievements in practice marks the end of a teaching reform project, and also the starting point for deepening research and reform. The application of teaching reform project achievements in practice signifies that the project has entered the conclusion phase and reached its end point, as it has to some extent addressed the initially preset school-based practical issues and fulfilled its primary tasks and missions. However, from another perspective, the application of achievements in practice also serves as the starting point for deepening research and reform. Firstly, problems encountered in practice are often complex and variable, and a single project often cannot fully resolve them, necessitating further research and reform. Secondly, the promotion of reform achievements on a larger scale can effectively test the quality of the results, refine higher-quality achievements, and enhance the influence of project outcomes.

The final outcomes of educational reform projects encompass not only various theoretical achievements but also diverse practical results. Theoretical achievements include forms such as academic papers and scholarly works. To address issues in teaching practice, the research team employs scientific research methods to conduct in-depth studies on the reform targets. This research does not exclude drawing on the reform exploration achievements of other schools. It also includes a literature review of existing research on related issues. These studies provide support for formulating scientific and effective action plans for subsequent reforms. The scientificity and effectiveness of research findings are tested in subsequent actions and continuously improved during the reform process. The main forms of practical outcomes include survey reports, reform implementation plans, and other results. Practical outcomes are generated during the process of problem-solving and provide a clear description of the problem-solving process, influencing factors, technical routes, specific measures, and reform effectiveness. They are highly operational and differ from general educational research outcomes, which "are keen on thinking at a purely philosophical and abstract level, blindly adopting the discourse system of Western educational scholars, overly focusing on speculation, and there is a significant gap between their discourse expression and that of educational practitioners" [5]. Therefore, the significance of promoting and drawing on these outcomes is even stronger.

3 DILEMMA EXPLORATION: ANALYSIS OF THE DILEMMA IN PROMOTING ACHIEVEMENTS BASED ON PRACTICAL CHARACTERISTICS

The "practical characteristics" and "outcome promotion" of educational reform projects are dialectically related. The "practical characteristics" of educational reform projects constrain the methods and forms of "outcome promotion", and influence the paths and effects of "outcome promotion". We can delve into the root causes of the difficulties in promoting the outcomes of educational reform projects through the dialectical relationship between "practical characteristics" and "outcome promotion".

3.1 Dilemma 1: "The School-based Characteristics are Distinct, but the Promotion Significance is Limited"

Some schools, due to their educational reform projects stemming from "school-based practices," exhibit distinct "school-based characteristics" in their reform outcomes. Consequently, they exhibit "insufficient confidence" in promoting these outcomes, and harbor biases against drawing on the educational reform achievements of other schools, deeming it "of little significance." These attitudes reflect a lack of dialectical understanding of the "practicality" of educational reform projects.

On the one hand, educational reform projects indeed bear distinct "school-based" characteristics. Educational reform projects originate from the educational teaching and practice issues of the school itself, and their outcomes are produced under various comprehensive factors in the natural environment of the school. They inevitably bear distinct "school-based" characteristics. When the outcomes are promoted to other schools, different subjective and objective conditions such as school history and region will inevitably affect the promotion process. This is an objective reality.

On the other hand, common challenges and ongoing practical explorations necessitate the promotion and reference of achievements. Although educational reform outcomes stem from school-based practices, universities often face similar environments and issues. Many problems in university education and teaching are not solely caused by the universities themselves. Many issues arise from changes in the external environment, such as adjustments in educational policies, transformation and upgrading of industries, and changes in talent demands of industries and enterprises, which lead to new problems and contradictions. Universities need to adapt to these external environmental changes and make reform adjustments. These external environments do not affect only one university, nor do they require only one university to respond to these changes. Facing common challenges and external environments, universities can learn from each other's reform achievements during the exploration process and complement each other's strengths.

3.2 Dilemma 2: "Low Quality of Results and Low Promotional Value"

Some people believe that the primary subjects of educational reform project research are "frontline teachers and educational administrators". They lack rigorous academic training in educational research, resulting in "lower quality outcomes and limited promotional value". This perception fails to fully grasp the current model of team formation for educational reform projects, nor does it accurately understand the positive role of "frontline teachers and educational administrators" in enhancing the quality of outcomes and promoting them.

The composition of educational reform project teams encompasses both "independent mode" and "collaborative mode". Currently, the composition of educational reform project teams includes two modes. The first mode is the "independent mode": in this mode, practitioners conduct research independently. The research subjects are "frontline teachers and educational administrators", who do not require the assistance and guidance of experts (traditional "researchers"). While some "frontline teachers and educational administrators" possess high research skills, there are indeed some who lack rigorous academic training in educational research, resulting in "lower quality outcomes". The second mode is the "collaborative mode", in which experts (or traditional "researchers") and practitioners form a partnership. As "consultants", they help practitioners form hypotheses, plan actions, evaluate the process and outcomes of actions. The motivation for research comes from the practitioners themselves, who use their own wisdom to select topics and guide actions. In the "collaborative mode", issues such as the lack of scientific rigor in the research process and the use of inappropriate research methods by "frontline teachers and educational administrators" can be effectively addressed [6]. This can, to some extent, improve the quality of educational reform project outcomes. Moreover, in collaboration with "experts", the research capabilities of "frontline teachers and educational administrators" are significantly enhanced, providing support for their subsequent independent conduct of educational reform project research.

The participation of "frontline teachers and educational administrators" can effectively promote the depth of outcomes, verify the quality of outcomes, and enhance the operability of outcomes, which is more conducive to the promotion of outcomes. "Frontline teachers and educational administrators" can mobilize corresponding human and material resources to effectively promote the deepening of reforms, thus providing assistance for the in-depth research of projects. Some research has stalled, partly due to the consistent failure to deeply promote practical reforms. As users of research results, "frontline teachers and educational administrators" can effectively verify the quality of outcomes and provide timely feedback, thereby improving the quality of outcomes. As participants in research and actors in reform, "frontline teachers and educational administrators" can accurately describe the complexity of practice during the project's advancement, enhance the operability of outcomes, and make it easier for other schools to directly learn from and use project outcomes.

3.3 Dilemma 3: "Insufficient Motivation within the Project Team, and Low Enthusiasm for Promoting Project Outcomes"

In the promotion of educational reform project outcomes, a relatively common phenomenon often exists, which is the "lack of motivation within the project team and low enthusiasm for promoting the outcomes". In fact, we can analyze its deep-seated root causes from the practical perspective of educational reform projects.

The resolution of practical issues in educational reform, to some extent, signifies the end of the project. Once the practical issues related to school-based practices are resolved, the educational reform project enters a state of conclusion, which means the end of the project. This is also the main reason for the lack of motivation and enthusiasm among some educational reform   project teams. Moreover, promoting the project requires a significant amount of time, energy, and resources. We can also confirm this phenomenon from another perspective: the most active advocates for promoting the results are the educational reform project management departments and educational administrative departments.

The conclusion of a teaching reform project does not signify the end of research. Practical issues are often complex and ever-changing, and the countermeasures proposed in a particular teaching reform project are often not the optimal solution. During the process of promoting the results outside the school, comparative analysis can provide more ideas and inspiration for solving teaching and practical issues in our school. On the other hand, through multi-school practice during the promotion process, the quality, application scope, and influence of the results can be improved, enhancing the academic status of the project team teachers. This is also one of the   intrinsic motivations for some teachers to promote the results.

4 RETURNING TO PRACTICE: OPTIMIZATION STRATEGIES FOR PROMOTING EDUCATIONAL REFORM ACHIEVEMENTS

4.1 Source of Achievements: Selecting Widely Applicable Teaching Practice Issues for Project Initiation to Enhance the Scalability of Achievements

The successful promotion of educational reform outcomes primarily lies in the fact that the practical issues addressed by educational reform projects are widespread problems. Before initiating an educational reform project, selecting teaching issues that are prevalent in school teaching practices can not only facilitate the wider promotion of project outcomes but also enhance the efficiency of project funding utilization. When determining the guidelines for educational reform projects, a combination of "top-down" and "bottom-up" approaches can be adopted to carefully select widespread practical issues. "Top-down" refers to in-depth research on relevant national educational and teaching policies, as well as hotspots and difficulties in education and teaching. "Bottom-up" refers to collecting information from frontline teachers and educational administrators about the key and difficult issues in their school's educational and teaching reforms. Then, the project department will sort out the widespread issues in school teaching practices based on the relevant information collected through both "top-down" and "bottom-up" approaches, and formulate a draft of the educational reform project guidelines. These guidelines will then be reviewed and discussed by the school's teaching work committee or academic committee before being finalized.

4.2 Achievement Formation: Improve the Quality of Educational Reform Achievements and Enhance Their Promotional Value

High-quality educational reform outcomes serve as a crucial foundation for promotion. Currently, some educational reform project teams primarily consist of frontline teachers and teaching administrators. In particular, science and engineering teachers generally embrace the paradigm of scientific research and are not well-versed in the humanistic paradigm of teaching research, which emphasizes action and experiential research. The overall quality of educational reform project research is not high and has been widely criticized. In addition to strengthening relevant educational research training for teachers, establishing reform project teams with diverse participation and cross-school collaboration is an important way to improve the quality of educational reform outcomes. "Experts or researchers" can form collaborative project teams with "frontline teachers and education administrators". "Experts or researchers" can appear as "supporters" or "collaborators", assisting "frontline teachers and education administrators" in scientifically analyzing problems, developing scientific and reasonable research and reform plans, and providing timely consultation and reference for issues arising during the research and reform process. This "collaborative model" is also an important way to enhance the research level of "frontline teachers and education administrators". Furthermore, "frontline teachers and education administrators" can form cross-school teams to ensure shared responsibility and results in the process of promoting research topics, which can, to a certain extent, guarantee the in-depth promotion and application of research outcomes.

4.3 Achievement Content: Enrich the Forms of Educational Reform Achievements and Enhance the Pertinence Of Promotion

The forms of educational reform achievements should be diversified, providing different types of outcomes tailored to different promotion targets. For example, for educational administrative leaders, outcomes such as decision-making consultation research reports can be provided to support their scientific decision-making. "The focus should be on

promoting the value of the achievement in theory and practice, and clearly indicating which 'difficult' and 'hot' issues in local education and teaching can be solved through the promotion of this achievement, in order to attract the attention of administrative leaders. In this way, not only will it be easily adopted in leaders' planning, decision-making, arrangement, and summary work, but it will also receive strong support during the promotion process of the achievement" [7]. For grassroots teachers and teaching administrators facing similar problems, outcomes such as brief introductions to the achievements and reform implementation action plans can be provided, making it easy for them to directly imitate and adopt the achievements. The forms of the achievements should be more specific, intuitive, and easy to imitate and operate, without being overly theoretical, reducing the difficulty of imitation and making it acceptable to both schools and teachers. For educational researchers, outcomes such as research reports, papers, and academic monographs can be provided. These achievements mainly reveal and summarize the laws and principles of educational science, inspire educators to continuously improve their way of thinking, and analyze and solve new situations and problems in education and teaching from a new perspective. The achievements focus on describing the research ideas, methods, innovativeness, and normativity.

4.4 Achievement Demonstration: Establish a Platform for Exchanging Educational Reform Achievements to Enhance the Convenience of Promoting These Achievements

From the previous analysis, we can see that for the project team, solving the practical problems of educational reform, to some extent, signifies the end of the project. Promoting the achievements is not the primary task of the teachers in the project team. Moreover, promoting the achievements actually requires a significant amount of time and effort, and mobilizing a substantial amount of resources to advance the work. The educational management departments that have the most positive view towards the value of promoting educational reform achievements have the responsibility and obligation to build a platform for exchanging educational reform achievements and promote the sharing and application of these achievements. The platform for exchanging educational reform achievements includes school-level, regional-level, and national-level platforms. This platform is conducive to accumulating practical experience in teaching development and is a valuable asset for schools and the country. At the same time, it facilitates the avoidance of duplicate projects when initiating projects, thereby improving the efficiency of the use of educational funds. For teachers from different schools, using relevant theoretical and practical achievements on this platform can effectively enhance the efficiency of resource utilization.

5 CONCLUSION

The promotion and application of achievements are two aspects. "Promotion refers to the process of systematically and step-by-step disseminating the content of achievements and applying them within a certain scope, so as to transform them into educational benefits. Application refers to the process of achievements being accepted, understood, internalized, transformed, and applied in educational practice by other educators" [8]. "Promotion" and "application" have their respective focuses, with "promotion" being the premise and "application" being the essence. This article mainly expounds on the logical relationship between the essential attributes of educational reform projects and the promotion of achievements from the perspective of the supply side. In fact, the process of promoting achievements to effective application and transforming them into teaching productivity in one's own school is complex and requires in-depth research and exploration.

COMPETING INTERESTS

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

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REFERENCES

[1] Yi Haihua. Misconceptions and Countermeasures in the Promotion and Application of Educational Research Achievements. Chinese Journal of Education, 2017(4): 16-20.
[2] Zou Yongsong, Chen Jinjiang. Returning to Practice: Empowering Teaching and Research Projects to Truly Drive Teaching Reform. China Higher Education, 2012(32): 28-30.
[3] Zhou Xiang, Wang Xiaomei, Liu Zhimeng. Research Progress and Hotspot Analysis of Vocational Education in China: Statistical Analysis of Vocational Education Research Papers from Chinese Universities in 2023. China Higher Education Research, 2024(07): 95-108. DOI: 10.16298/j.cnki.1004-3667.2024.07.14.
[4] Chen Xiangming. What is Action Research?. Educational Research and Experimentation, 1999(2): 60-68.
[5] Yang Xuhui. Vocational Education Research from the Perspective of an Independent Knowledge System: Problems, Causes, and Countermeasures. Chinese Vocational and Technical Education, 2025(13): 41-49.

[6] Zheng Jinzhou. Action Research: A Research Method That Is Gaining Increasing Attention. Shanghai Higher Education Research, 1997(1): 23-27.

[7] Xiang Zhikang, Ruan Longpei, Zhang Shengyuan, et al. Discussion on the Promotion of Educational Research Findings. Shanghai Research on Education, 1995(03): 12-20. DOI: 10.16194/j.cnki.31-1059/g4.1995.03.004.

[8] Zhang Zhiwei, Wang Zhilin. Process Management of the Promotion and Application of Educational Research Achievements. Shanghai Educational Research, 2004(12): 68-69.

DIGITAL EMPOWERMENT IN K-12 CHINESE WRITING INSTRUCTION: RESEARCH ON PERSONALIZED LEARNING STRATEGIES AND PRACTICE MODELS

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Abstract: Addressing the core challenges of "homogenized teaching models" and "delayed feedback" inherent in traditional K-12 Chinese writing instruction, this study aims to construct a new data-driven paradigm for personalized writing instruction. Employing a mixed-methods research design, the study utilizes quasi-experimental methods and triangulation strategies to verify the effectiveness of digital tools throughout the entire writing process.First, the study constructs a student-centered, four-dimensional personalized learning strategy model comprising "diagnosis, intervention, feedback, and assessment," alongside a functional mapping system for digital tools. Second, empirical analysis based on pre-test, post-test, and delayed-test data reveals that this strategy significantly enhances students' writing performance, language construction capabilities, and metacognitive levels, while demonstrating differential gains among students with varying proficiency levels. Finally, the study explores the synergistic mechanism between AI-based intelligent correction and peer review.This study not only confirms the efficacy of digital tools in resolving the conflict between individual student needs and large-scale instruction but also provides a theoretical basis and practical pathways for resource allocation, teacher professional development, and the establishment of ethical norms within the context of the digital transformation of education.

Keywords: Digital writing instruction; Personalized learning strategies; Data-driven; Core literacy; Education; K-12 Chinese language

1 INTRODUCTION

1.1 The Context of the Era of Digital Transformation in Education

With the rapid development of information technology, artificial intelligence (AI) and big data are reshaping the field of education, playing a pivotal role particularly in the transformation of instructional modalities. Currently, educational informatization has become a significant trend in global educational reform, and the contextual landscape of digital education transformation is primarily manifested in the following aspects, as illustrated in Figure 1. First, the explicit requirements regarding the integration of information technology outlined in the New Curriculum Standards provide clear policy orientation for educational digitization. These standards emphasize the cultivation of students' information literacy and innovative capabilities, necessitating that teachers actively integrate information technology into instruction to facilitate students' adaptation to the learning demands of the digital age. For instance, the application of intelligent tutoring systems can offer personalized learning pathways for students, thereby achieving the objectives of differentiated instruction. Second, the convergence of artificial intelligence and big data technologies has brought revolutionary changes to instructional modalities[1]. The application of AI technologies in education, such as intelligent tutoring systems and automated grading systems, enables the real-time collection and analysis of student learning data, providing teachers with precise instructional feedback. Statistics indicate that students utilizing AI-assisted instruction demonstrate an average increase in learning efficiency of over 15%. Furthermore, big data analytics can reveal deep-seated patterns in student learning behaviors, contributing to the optimization of pedagogical strategies. Through the mining of student learning data, specific difficulties and weaknesses encountered during the learning process can be identified, allowing for the adjustment of teaching methods and content to enhance instructional effectiveness. Currently, Chinese writing instruction in primary and secondary schools faces a series of practical dilemmas. The phenomenon of instructional homogenization makes it difficult to satisfy students' personalized needs, exacerbating the contradiction between individual differences and unified teaching models. Simultaneously, the latency of feedback mechanisms severely constrains the iterative improvement of students' writing abilities. Therefore, within the context of digital education transformation, establishing a new paradigm of data-driven, personalized writing instruction appears particularly crucial[2]. This paradigm can utilize real-time data monitoring and intelligent feedback to assist students in identifying and correcting errors during the writing process, thereby enhancing their writing proficiency. In conclusion, the era of digital education transformation demands that educators possess not only keen technological insight but also profound educational understanding to adapt to the opportunities and challenges brought about by this transformation.
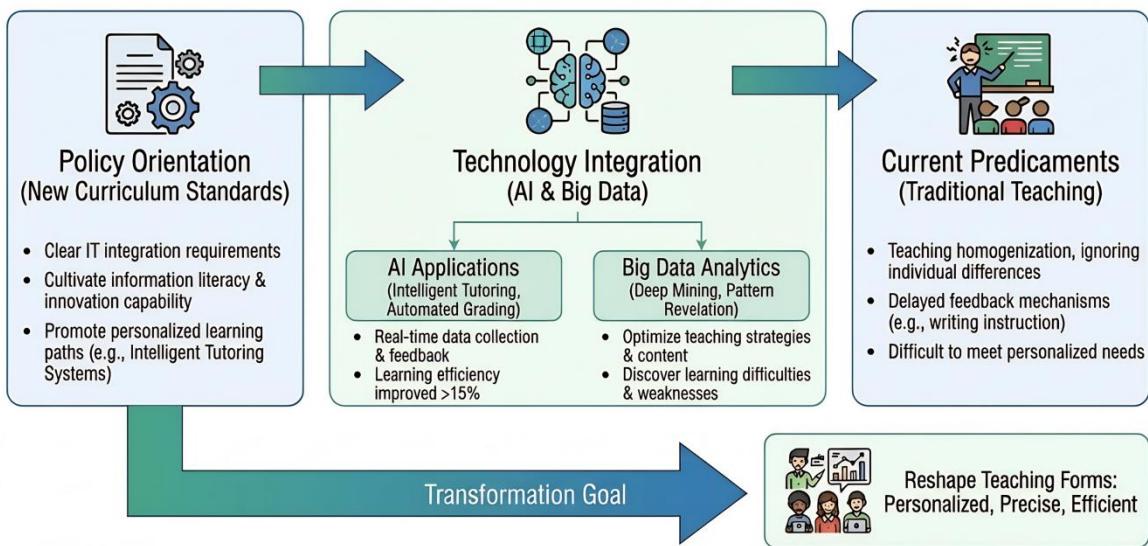
Figure 1 AI & Big Data Driven Digital Transformation in Education: Context, Applications, and Challenges

1.2 The Reality Dilemmas of Writing Instruction in Primary and Secondary Schools

In current educational practice, Chinese writing instruction in primary and secondary schools faces multiple dilemmas. Among these, feedback latency is a critical factor constraining the iterative improvement of students' writing abilities. Since assessment and feedback in writing instruction usually rely on teachers' individual judgments, this limits the speed and quality of feedback to a certain extent. Research indicates that timely and targeted feedback is paramount for the development of writing skills[3]. On one hand, the latency of feedback causes students to remain unaware of problems in their writing for an extended period, preventing timely adjustment and improvement. This delay not only diminishes the efficacy of writing training but also lowers students' learning motivation. For instance, it may take a week or longer from submission to feedback, during which time students may have already forgotten their train of thought and feelings at the time of writing. On the other hand, due to increased teacher workload, traditional feedback methods often focus on the final product of the composition, neglecting the importance of the writing process. Such methods make it difficult to provide real-time monitoring and guidance on the development of thinking and language expression during the writing process. Statistics show that when grading, teachers often focus more on the standardization of language and content, while guidance on writing strategies and thinking processes is relatively limited. Furthermore, the issue of feedback homogenization merits attention. Due to a lack of personalized feedback, individual differences among students are not fully respected or considered. Every student has a unique writing style and way of thinking; standardized feedback fails to adequately meet personalized needs, further exacerbating the contradiction between instructional homogenization and individual differences. Therefore, to overcome these dilemmas, it is necessary to explore new pedagogical pathways[4]. By introducing a data-driven personalized writing instruction paradigm, dynamic monitoring and immediate feedback of the entire writing process can be achieved, thereby improving the efficiency and effectiveness of instruction. This paradigm shift not only facilitates the resolution of the feedback lag problem but also provides personalized guidance for every student, promoting the continuous improvement of their writing capabilities.

1.3 Research Objectives and Core Value Positioning

This study aims to construct a new paradigm of data-driven personalized writing instruction to address issues such as the intensifying contradiction between instructional homogenization and individual differences, and the constraint of feedback lag on the iterative improvement of writing ability in current primary and secondary school Chinese writing instruction. Specifically, the research objectives and core value positioning are as follows, as illustrated in Figure 2: First, by integrating personalized learning theories and writing instruction theories, a student-centered four-dimensional driver structure is designed, comprising diagnosis, intervention, feedback, and assessment. This structure aims to achieve dynamic regulation through data flow permeating the entire writing process, facilitating the personalized improvement of each student's writing ability[5]. The core of this paradigm lies in identifying individual differences through data-driven strategies and providing customized writing support, thereby driving the digital transformation of writing instruction. Second, a digital tool functional mapping system is constructed to provide technical support for writing instruction. In the front-end ideation stage, mind mapping tools and intelligent content recommendations are utilized to assist creative conception; in the mid-stage drafting phase, real-time grammar detection and style adaptation suggestions are implemented to help polish the text; in the back-end revision stage, multi-dimensional evaluation reports and revision path navigation are provided to guide self-correction. The establishment of this system aims to enhance the effectiveness and efficiency of writing instruction and achieve the optimal allocation of writing resources. Third, the research is dedicated to building a support architecture for core competency development, providing support for students' comprehensive development through the design of data-based representation indicators for language

construction ability and dynamic monitoring dimensions for cognitive development levels. This not only aids in the enhancement of writing ability but also promotes the synchronous improvement of cognitive quality and language literacy. Furthermore, the core value of this study lies in promoting the bidirectional empowerment of theoretical innovation and frontline practice. On one hand, the study provides theoretical support and reference for future research in related fields through the construction of a theoretical framework; on the other hand, through empirical research, it verifies the validity of the proposed strategies, providing practical guidance for the reform of primary and secondary writing instruction. Statistics indicate that adopting the data-driven personalized writing instruction paradigm significantly improves students' writing abilities[6]. For example, in a pilot study in a certain region, the experimental group's writing scores increased by an average of 15%, and individual differences were effectively addressed. These results demonstrate that the theoretical and practical value of this research is significant for promoting educational equity and improving educational quality.
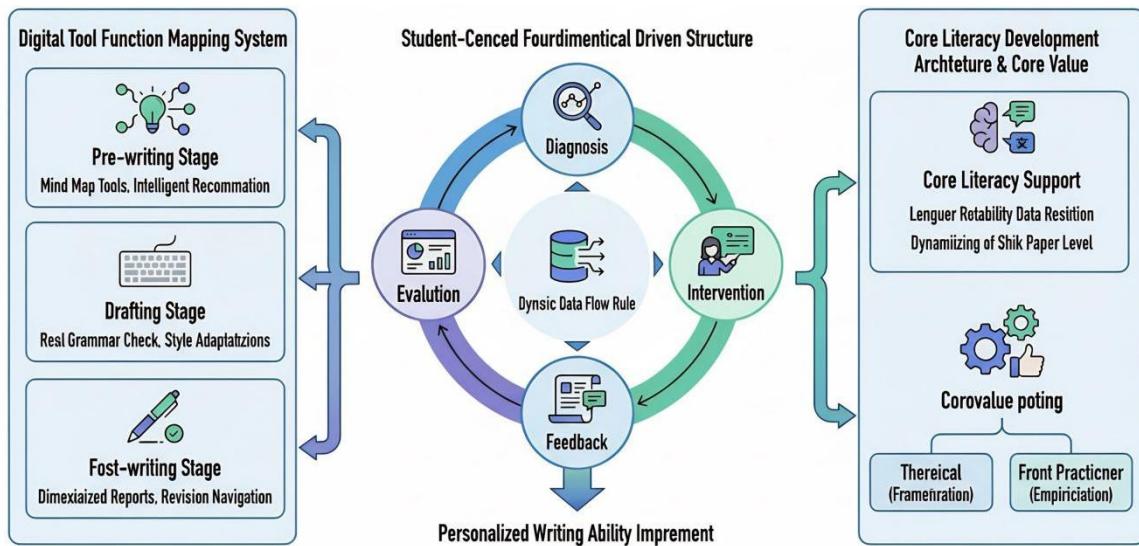
Figure 2 Research Framework for Data-Driven Personalized Writing Teaching Paradigm

2 LITERATURE REVIEW

2.1 The Developmental Trajectory of Personalized Learning Theory

The development trajectory of personalized learning theory traces back to early explorations of differentiated instruction, centering on attending to individual differences and achieving personalized adaptation of instructional content. Differentiated instruction posits that due to variations in students' knowledge backgrounds, cognitive styles, and learning motivations, uniform teaching methods often fail to meet all students' learning needs. With the advancement of educational technology, personalized learning theory has gradually integrated concepts of computer-assisted instruction, propelling the birth of adaptive learning systems. These systems utilize modern educational technologies, such as artificial intelligence and big data analytics, to monitor students' learning processes in real-time and dynamically adjust learning content based on personalized characteristics. The development of such systems has evolved from simple personalized recommendations to the construction of complex cognitive models, enabling more precise targeting of student learning needs and the provision of customized learning resources. In recent years, embodied cognition theory has offered a new perspective for personalized learning theory. Embodied cognition emphasizes the vital role of learners' physical activities, perception, and situational interaction in the learning process. Within the context of personalized learning, tool interaction and learning perception have become research hotspots. Studies indicate that tools serve not merely as learning resources but as extensions of learners' cognitive activities, influencing learning outcomes by altering learners' cognitive load and interaction modes[7]. In the domain of tool interaction, researchers have explored the impact of various digital tools on the learning process. For instance, intelligent tutoring systems can simulate the guidance of human teachers, providing personalized learning suggestions; cognitive tools, such as concept maps and mind maps, help learners organize and integrate knowledge by facilitating thinking activities. Meanwhile, research on learning perception focuses on learners' psychological experiences when using these tools, such as learning motivation, self-efficacy, and cognitive load. Statistics show that personalized learning systems can significantly enhance learners' learning effectiveness and satisfaction. However, research in this field is still in a developmental stage, facing challenges regarding how to ensure system scalability, usability, and cost-effectiveness while maintaining personalized learning effects. As technology progresses and theories deepen, the development of personalized learning theory will continue to provide new methods and insights for educational practice.

2.2 Core Dimensions of Writing Instruction Theory

As an application of social constructivist pedagogical concepts in writing instruction, peer assessment is receiving increasing attention from educational researchers. Social constructivism holds that learning is a social process, and knowledge is constructed through interactions between individuals and others. The value of peer assessment lies in its ability to promote the enhancement of writing skills and cognitive development through cooperation and communication among students. Research indicates that peer assessment helps students examine their own writing from different perspectives, thereby improving writing quality. In the writing instruction process, students are not only recipients of knowledge but also co-creators. Through interaction among peers, students can obtain immediate feedback, which includes not only guidance on writing techniques but also suggestions regarding content and structure. The value of peer assessment is manifested in several aspects: First, peer assessment helps cultivate students' critical thinking and self-reflection abilities. When evaluating peers' writing, students need to employ critical thinking to analyze the strengths and weaknesses of the text; this analytical ability is equally applicable when evaluating their own work. Furthermore, by reflecting on peer feedback, students can better understand their own writing processes, thus promoting the enhancement of self-reflection abilities. Second, peer assessment fosters cooperation and communication among students[8]. During the mutual evaluation process, students need to communicate with each other and share writing insights, which not only enhances friendship among students but also promotes the dissemination of writing skills. Through collaboration, students can better understand writing norms and techniques, thereby improving their writing levels. Third, peer assessment helps stimulate students' learning motivation. In the process of evaluating peers, students can experience the fun and value of writing; this positive emotional experience can stimulate students' interest in learning, thereby improving the actual effectiveness of writing instruction. Additionally, peer assessment can promote the development of students' metacognitive abilities. When evaluating peers' writing, students need to use metacognitive strategies such as planning, monitoring, and evaluating, which are crucial for improving writing abilities. However, the implementation of peer assessment also faces challenges, such as the subjectivity of evaluation standards and the assurance of evaluation quality. Therefore, when guiding peer assessment, teachers need to provide clear standards and guidance to ensure the fairness and validity of the evaluation. Statistics show that in schools adopting peer assessment, students' writing abilities have improved significantly. For example, a study targeting high school students found that after one semester of peer assessment training, students' writing scores increased by an average of 15%. This indicates that the value of peer assessment in writing instruction cannot be ignored. In summary, as one of the core dimensions of writing instruction theory, peer assessment not only helps improve students' writing abilities but also promotes the development of students' critical thinking, self-reflection, and collaborative communication skills. Therefore, in future writing instruction, teachers should fully tap into the potential of peer assessment and create more interaction opportunities for students to achieve the goals of writing instruction[9].

2.3 Application Research of Digital Tools in Language Teaching

As a type of digital tool, online collaborative platforms have brought new perspectives and methods to language teaching. Empirical research indicates that such platforms can facilitate the formation of writing communities, thereby enhancing students' writing abilities. By establishing online collaborative platforms, students can engage in writing exercises, interactive communication, and peer assessment on the platform, thus breaking the spatiotemporal limitations of traditional writing instruction. First, online collaborative platforms help stimulate students' interest and motivation in writing. Students can publish their own works on the platform and receive immediate feedback from peers and teachers; this interactivity can ignite students' enthusiasm for writing. Statistics show that among students using online collaborative platforms for writing, over 80% expressed a stronger interest in writing. Second, online collaborative platforms help improve the quality of students' writing[10]. The platforms provide functions such as real-time error correction, grammar detection, and style suggestions, allowing students to discover and correct their errors in a timely manner during the writing process. In addition, the platforms support peer assessment, enabling students to read, evaluate, and modify each other's works, thereby improving writing levels. Research shows that compositions that have undergone peer assessment are generally of higher quality than those that have not. Furthermore, online collaborative platforms help cultivate students' collaborative and social capabilities. On the platform, students need to communicate and collaborate effectively with peers to jointly complete writing tasks. This interactivity helps cultivate students' team awareness and collaborative abilities. Simultaneously, by reading and evaluating others' works, students can broaden their horizons and improve their social skills. However, the application of online collaborative platforms in language teaching also faces some challenges. For instance, the use of platforms requires certain technical support, and the information technology literacy of teachers and students becomes a constraining factor[11]. Moreover, the use of certain functions on the platform may lead students to rely too heavily on technology, neglecting the cultivation of the essence of writing ability. In summary, as a digital tool, the application of online collaborative platforms in language teaching possesses significant advantages, capable of promoting the formation of writing communities and improving students' writing abilities and comprehensive qualities. However, at the same time, teachers and students should utilize platform functions rationally, focusing on the integration of information technology and language teaching to achieve better instructional effects.

2.4 Existing Research Gaps and Breakthroughs of This Study

Although existing research has made certain progress in the field of personalized writing instruction, significant gaps remain[12]. First, the systemic absence of a diagnosis-intervention closed-loop strategy model limits the precision and efficiency of writing instruction. Most studies remain at the level of optimizing individual instructional segments, lacking an overall design that integrates diagnosis, intervention, feedback, and assessment throughout the entire writing process, thus making it difficult to form a continuously effective instructional cycle. Second, the weak correlation between full-process writing support and core competencies represents another deficiency in existing research. Although digital tools are widely used in writing instruction, they are often limited to specific stages, such as grammar correction or peer assessment, neglecting the fact that writing is a complex mental activity process that requires comprehensive support from conception and drafting to revision. Furthermore, there is a lack of effective alignment between these tools and the development of students' core competencies, failing to fully mine the impact of data-driven personalized instruction on cultivating students' higher-order thinking and creativity. This study aims to break through the limitations of these existing studies. First, by constructing a student-centered four-dimensional driven personalized writing learning strategy model, the links of diagnosis, intervention, feedback, and assessment are organically combined to form a complete closed loop, aiming to improve the pertinence and continuity of instruction. Second, this study will develop a full-process writing support system that not only covers all stages of writing but also achieves dynamic regulation through data flow to provide personalized support. This system will combine mind mapping tools and intelligent material recommendations in the front-end ideation stage, real-time grammar detection and style adaptation suggestions in the mid-stage drafting phase, and multi-dimensional evaluation reports and revision path navigation in the back-end revision stage. Finally, this study will explore the correlation between digital tools and the development of core competencies, designing data-based representation indicators for language construction ability and dynamic monitoring dimensions for cognitive development levels, with the expectation of promoting students' comprehensive development in personalized writing instruction[13]. Through the aforementioned research design and practice, this study is expected to fill the gaps in existing research and provide a new theoretical framework and practical model for personalized writing instruction.

3 LITERATURE REVIEW

3.1 The Developmental Trajectory of Personalized Learning Theory

The development trajectory of personalized learning theory can be traced back to early explorations of differentiated instruction, the core of which lies in attending to individual differences and achieving the personalized adaptation of instructional content. The concept of differentiated instruction posits that due to variations in students' knowledge backgrounds, cognitive styles, and learning motivations, uniform teaching methods often fail to meet the learning needs of all students. With the development of educational technology, personalized learning theory has gradually integrated the concepts of computer-assisted instruction, propelling the birth of adaptive learning systems. Adaptive learning systems utilize modern educational technologies, such as artificial intelligence and big data analytics, to monitor students' learning processes in real-time and dynamically adjust learning content based on personalized characteristics. The development of such systems has evolved from simple personalized recommendations to the construction of complex cognitive models, enabling a more precise targeting of student learning needs and the provision of customized learning resources. In recent years, embodied cognition theory has offered a new perspective for personalized learning theory. Embodied cognition emphasizes the vital role of learners' physical activities, perception, and situational interaction in the learning process. Within the context of personalized learning, tool interaction and learning perception have become research hotspots. Studies indicate that tools serve not merely as learning resources but as extensions of learners' cognitive activities, capable of influencing learning outcomes by altering learners' cognitive load and interaction modes. In the domain of tool interaction, researchers have explored the impact of various digital tools on the learning process[14-17]. For instance, intelligent tutoring systems can simulate the guidance of human teachers, providing personalized learning suggestions; cognitive tools, such as concept maps and mind maps, help learners organize and integrate knowledge by facilitating thinking activities. Meanwhile, research on learning perception focuses on learners' psychological experiences when using these tools, such as learning motivation, self-efficacy, and cognitive load. Statistics show that personalized learning systems can significantly enhance learners' learning effectiveness and satisfaction. However, research in this field is still in a developmental stage, facing challenges regarding how to ensure system scalability, usability, and cost-effectiveness while maintaining personalized learning effects. As technology progresses and theories deepen, the development of personalized learning theory will continue to provide new methods and insights for educational practice.

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comprehensive support from conception and drafting to revision. Furthermore, there is a lack of effective alignment between these tools and the development of students' core competencies, failing to fully mine the impact of data-driven personalized instruction on cultivating students' higher-order thinking and creativity. This study aims to break through the limitations of these existing studies. First, by constructing a student-centered four-dimensional driven personalized writing learning strategy model, the links of diagnosis, intervention, feedback, and assessment are organically combined to form a complete closed loop, aiming to improve the pertinence and continuity of instruction. Second, this study will develop a full-process writing support system that not only covers all stages of writing but also achieves dynamic regulation through data flow to provide personalized support. This system will combine mind mapping tools and intelligent material recommendations in the front-end ideation stage, real-time grammar detection and style adaptation suggestions in the mid-stage drafting phase, and multi-dimensional evaluation reports and revision path navigation in the back-end revision stage. Finally, this study will explore the correlation between digital tools and the development of core competencies, designing data-based representation indicators for language construction ability and dynamic monitoring dimensions for cognitive development levels, with the expectation of promoting students' comprehensive development in personalized writing instruction. Through the aforementioned research design and practice, this study is expected to fill the gaps in existing research and provide a new theoretical framework and practical model for personalized writing instruction.

4 THEORETICAL FRAMEWORK CONSTRUCTION

4.1 Personalized Writing Learning Strategy Model Design

In the context of the current digital transformation in education, the design of a personalized writing learning strategy model is of paramount importance. This model is student-centered and constructs a four-dimensional driving structure comprising diagnosis, intervention, feedback, and assessment. First, the design of the diagnostic dimension aims to identify students' weaknesses during the writing process, providing a basis for personalized intervention. This process involves collecting student learning data—such as writing content, style, and grammar usage—and utilizing data mining technology for in-depth analysis to reveal students' personalized needs. Second, the intervention dimension assists students in the writing preparation of the front-end ideation stage through intelligent tools, such as mind maps and intelligent material recommendations. In the mid-stage drafting phase, real-time grammar detection and style adaptation suggestions help students correct errors in a timely manner and improve writing quality. In the back-end revision stage, multi-dimensional evaluation reports and revision path navigation assist students in self-feedback and correction. The dynamic regulation mechanism, where data flows through the entire writing process, is the core of the model. This mechanism continuously adjusts learning strategies and instructional interventions by monitoring students' writing behaviors and results in real-time, thereby achieving personalized writing guidance. For example, by analyzing students' writing speed, revision frequency, and error types, the system can dynamically adjust writing suggestions and feedback content to better fit the students' actual needs. The design of the digital tool functional mapping system aims to combine various educational technology tools with different stages of writing instruction. In the front-end ideation stage, mind mapping tools help students organize their thoughts, while intelligent material recommendations can provide information relevant to the writing topic, stimulating students' inspiration. In the mid-stage drafting phase, real-time grammar detection and style adaptation suggestions help students identify and correct errors promptly, optimizing writing style. In the back-end revision stage, multi-dimensional evaluation reports provide detailed revision suggestions, while revision path navigation guides students on how to revise effectively. Furthermore, the construction of the support architecture for core competency development focuses on enhancing students' language construction abilities and cognitive development levels. Data-based representation indicators for language construction ability, such as vocabulary richness and sentence structure complexity, can assess students' writing levels through quantitative analysis. The dynamic monitoring dimension design for cognitive development levels includes aspects such as logic and critical thinking, promoting the enhancement of students' thinking abilities through periodic assessment and feedback. Research indicates that the design of the personalized writing learning strategy model can effectively improve students' writing abilities. For instance, after a period of personalized writing training, the writing scores of students in the experimental group were significantly higher than those in the control group. Additionally, students showed marked improvements in metacognitive abilities and learning motivation. These findings further verify the effectiveness of the personalized writing learning strategy model.

4.2 Digital Tool Functional Mapping System

In the back-end revision stage, the functional mapping system of digital tools is primarily manifested in the construction of multi-dimensional evaluation reports and revision path navigation. This system provides in-depth feedback on students' writing outcomes through intelligent text analysis technology and guides students in making effective revisions. First, the multi-dimensional evaluation report is a product based on natural language processing technology. This report includes not only traditional spelling and grammar error detection but also analyses across multiple dimensions such as discourse structure, vocabulary richness, and clarity of expression. For example, statistics show that students using this report improved their scores on article structure by an average of 15%. Quantitative analysis of these dimensions helps students comprehensively understand their writing levels and make improvements in specific areas. Second, revision path navigation is another key function of the digital tools. This function intelligently recommends

directions and steps for improvement by analyzing data from the students' writing process. For instance, if a student uses repetitive vocabulary excessively during writing, the system will recommend synonym replacements while guiding the student to maintain the original meaning and style of the article. Such personalized navigation can significantly improve students' revision efficiency and shorten the writing cycle. Furthermore, this functional mapping system emphasizes dynamic adjustment and immediate feedback. During the revision process, students can see the effects of their modifications in real-time and compare them with the system's suggestions, thereby promoting the enhancement of self-assessment and self-adjustment capabilities. Research shows that after a period of training, students' self-confidence and independent problem-solving abilities when facing writing tasks are significantly strengthened. However, the functional mapping system of digital tools also faces certain challenges. For example, ensuring the accuracy and fairness of evaluation reports to avoid misleading students due to algorithmic bias is crucial. Additionally, customizing tool functions for students of different grades and writing levels to adapt to their specific learning needs remains a focus for future research. In conclusion, the digital tool functional mapping system plays an important role in the back-end revision stage of writing instruction; through multi-dimensional evaluation reports and revision path navigation, it provides comprehensive, personalized writing support for students, helping to enhance their writing abilities and core competencies. With continuous technological progress, this system is expected to receive wider application and optimization in future writing instruction.

4.3 Core Competency Development Support Architecture

The construction of the support architecture for core competency development aims to promote students' language construction abilities and cognitive development levels through data-driven personalized writing instruction. First, data-based representation indicators of language construction ability form the foundation of the architecture. This indicator system should cover the accuracy, fluency, richness, and logic of language expression; through intelligent analysis systems, data such as students' learning behaviors and writing outcomes are quantified to form traceable and evaluable trajectories of capability development. Second, the design of dynamic monitoring dimensions for cognitive development levels is key to the development of core competencies. This dimension should include creative thinking, critical thinking, and logical reasoning abilities. By monitoring students' learning processes in real-time and recording data on cognitive activities, the depth and breadth of students' thinking can be analyzed to provide a basis for instructional intervention. In terms of data-based representation of language construction ability, natural language processing technology can be used to extract features such as keywords, sentence structures, and discourse layout based on students' writing texts, combined with revision traces during the writing process, to assess the growth of their language expression abilities. For example, research indicates that students' self-correction behaviors during the writing process are positively correlated with the improvement of their language construction abilities. Regarding the dynamic monitoring of cognitive development levels, the level of thinking development can be measured by analyzing argumentation methods and problem-solving strategies in students' writing. Statistics show that after systematic thinking training, students' logical reasoning abilities in writing improve significantly, enabling them to organize arguments and evidence more effectively. In addition, the support architecture for core competency development must also consider the auxiliary role of digital tools. For instance, utilizing mind mapping tools can help students organize their thoughts before writing, while intelligent material recommendation functions can broaden students' knowledge horizons. During the writing process, real-time grammar detection and style adaptation suggestions can provide immediate feedback, promoting the progress of students' writing skills. After writing, multi-dimensional evaluation reports and revision path navigation provide students with detailed paths for self-improvement. In summary, the construction of the support architecture for core competency development requires not only focusing on the enhancement of language and thinking abilities but also combining the advantages of digital tools to provide personalized, all-encompassing support for students. The implementation of this architecture will help improve the actual effectiveness of writing instruction, cultivate students' core competencies, and lay a solid foundation for their future learning and professional development.

5 RESEARCH METHODS AND IMPLEMENTATION PATH

5.1 Mixed Research Design Framework

The mixed research design framework aims to combine the strengths of quantitative and qualitative research to enhance the depth and breadth of the study. In this research, the mixed design framework integrates quantitative data with qualitative interviews through triangulation, aiming to ensure the credibility and validity of the research results. Specifically, this design framework consists of several core components. First, the study employs a quasi-experimental research method by establishing an experimental group and a control group, controlling variables to compare the differences in writing ability improvement between the two groups. The experimental group receives instructional intervention based on personalized writing learning strategies, while the control group continues to receive conventional instruction. This design helps identify the actual effects of the intervention measures, assessing the magnitude of writing ability improvement through data comparison from pre-tests and post-tests. Second, the application of triangulation reinforces the reliability of the research results. Quantitative data collection includes pre-tests, post-tests, and delayed tests of students' writing abilities to track long-term changes. Meanwhile, qualitative interviews are used to collect the subjective experiences of students and teachers, including their perceptions of instructional intervention, thoughts

during the writing process, and changes in learning motivation. These data mutually verify each other, providing a comprehensive research perspective. During the data collection process, special attention is paid to tracking process data, such as the number of times students revise compositions, the distribution of error types, and interaction frequency. These data help reveal the mechanisms behind the improvement of writing ability and provide empirical support for personalized writing learning strategies. Furthermore, the standardization of the implementation process is an important component of the mixed research design framework. The teacher training module aims to help teachers master the operational norms of digital tools and understand the implementation methods of personalized instructional strategies. The student guide manual instructs students on how to use personalized learning paths to achieve effective learning under self-drive. Through the implementation of the aforementioned mixed research design framework, this study aims to build a model that can effectively support personalized writing learning strategies and provide an empirical basis for the digital transformation of writing instruction through the integrated analysis of quantitative and qualitative data. Research indicates that the mixed research design not only helps reveal the mechanisms of student writing ability improvement but also provides a basis for educational practitioners to adjust instructional strategies.

5.2 Data Collection and Analysis System

Data collection is the foundation of research, while the analysis system determines the depth and breadth of the study. This research adopts a three-stage design of pre-test, post-test, and delayed test to assess writing ability. In the data collection phase, detailed process data is gathered through aspects such as the number of revisions students make during the writing process, the distribution of error types, and interaction frequency. The number of revisions serves as an indicator for measuring self-correction ability during writing, reflecting the active degree of students' thinking and their reflection and adjustment of writing content. By collecting data on the number of revisions from different students, individual learning differences and their growth trajectories during the writing process can be analyzed. Data on the distribution of error types helps identify common errors in student writing, such as grammatical errors, spelling mistakes, and punctuation errors. By statistically analyzing the distribution of different error types, instructional intervention strategies can be designed specifically to help students overcome these common writing obstacles. Data collection regarding interaction frequency involves interactive behaviors between students and teachers, as well as among peers. This includes participation in classroom discussions, activity levels in peer assessment, and interactions on online platforms. The analysis of these data helps understand the processes of knowledge sharing and collaborative progress within the learning community. Regarding the analysis system, this study employs a combination of quantitative and qualitative methods. Quantitative analysis mainly includes the quantified assessment of writing ability, measuring the magnitude of writing ability improvement through significance testing of the score differences between the experimental group and the control group. Additionally, the gain magnitudes of students with different proficiency levels are compared to assess the applicability of the strategy to students of different tiers. Qualitative analysis focuses on the qualitative analysis of core competency development, such as analyzing the improvement of metacognitive abilities through classroom observation records and understanding changes in learning motivation through coding results from student interviews. These analyses help reveal the deep-seated impacts of the digital transformation of writing instruction. At the same time, the assessment of tool usage efficacy is also an important part of the analysis system. Consistency analysis between AI grading accuracy and manual re-verification can verify the reliability and validity of the AI grading system. Analysis of the correlation between peer assessment quality and social network density helps understand the mechanism by which peer interaction promotes writing ability improvement. In summary, the data collection and analysis system constructed in this study aims to comprehensively and systematically evaluate the effects of personalized writing instruction strategies, providing a scientific basis for subsequent educational reforms.

5.3 Implementation Process Standardization Scheme

The core of the implementation process standardization scheme lies in ensuring that teachers and students can effectively apply personalized writing learning strategies. First, the construction of the teacher training module is crucial. This module aims to enable teachers to master the operational norms of digital tools and understand the theoretical basis and practical application strategies of personalized writing instruction through a series of systematic training activities. Training content includes not only the basic operational procedures of tools but also how to adjust instructional strategies based on students' personalized needs and how to utilize data feedback for instructional decision-making. Second, the student guide manual is key to implementing personalized learning paths. The manual should detail the methods for using personalized learning paths, including how to use digital tools for self-diagnosis, how to select appropriate writing strategies based on diagnostic results, and how to obtain effective feedback and assessment during the writing process. Through the guide manual, students can clearly understand the entire process of personalized writing learning, thereby better participating in writing activities. During specific implementation, teachers and students should follow the following standardized process: first, teachers learn and master necessary skills and strategies through the training module; second, students use the guide manual to clarify how to use the personalized learning path; next, teachers use digital tools to conduct writing diagnoses for students and formulate personalized intervention plans based on diagnostic results; subsequently, students perform writing exercises according to the intervention plan and receive real-time feedback and assessment during the process; finally, teachers and students adjust teaching and learning strategies based on assessment results to achieve continuous optimization of instructional effects. To ensure the smooth

flow of implementation, the following measures are indispensable: first, establishing a support team composed of professionals and teachers to provide timely technical and instructional support; second, holding regular seminars and workshops to promote experience exchange and continuous learning among teachers; third, ensuring the continuity and effectiveness of the instructional process through regular monitoring and assessment. Furthermore, the implementation process standardization scheme should also focus on the continuous optimization of student personalized learning paths. This includes regularly updating the digital tool library to adapt to changing instructional needs and technological advancements; simultaneously, by collecting and analyzing student learning data, personalized writing instruction strategies are continuously adjusted and optimized to achieve more efficient improvement of writing capabilities and development of core competencies.

6 EMPIRICAL RESEARCH RESULTS

6.1 Quantitative Evidence of Writing Ability Improvement

In this study, we evaluated the impact of personalized writing instruction strategies on the improvement of students' writing abilities through quantitative methods. First, through comparative analysis of pre-tests and post-tests, the improvement in writing ability in the experimental group was significantly higher than that in the control group, as shown in Table 1. Specifically, the experimental group showed marked improvements in scores across various dimensions such as vocabulary usage, sentence structure, and discourse layout. Statistics indicate that the average score of the experimental group increased from 58.2 points in the baseline test to 72.6 points in the post-test, while the average score of the control group only increased from 55.1 points to 60.3 points. Further analysis revealed differences in the magnitude of gains among students with different baseline levels under personalized writing instruction strategies. For students with lower baseline levels, personalized instructional strategies helped bridge knowledge gaps and improve basic writing skills; for students with better baselines, the strategy was more effective in stimulating innovative thinking and promoting the maturity of writing style. For example, the reduction in grammatical and spelling errors was particularly significant among students with weak foundations, while students with better foundations demonstrated more significant progress in discourse structure and argument expression. Additionally, we further verified the persistence of writing ability improvement through delayed testing. The experimental group continued to outperform the control group in the delayed test, indicating that personalized writing instruction strategies not only rapidly improve students' writing abilities but that this improvement is also sustainable. Regarding specific skill improvements, the study found that students in the experimental group significantly improved the logic and completeness of their article structures when using mind mapping tools for writing training in the ideation stage. Simultaneously, the use of real-time grammar detection and style adaptation suggestions allowed students to correct errors in a timely manner during the drafting stage, improving writing quality. In the back-end revision stage, multi-dimensional evaluation reports and revision path navigation helped students deeply understand writing norms and optimize article expression. The above quantitative evidence indicates that personalized writing instruction strategies have significant effects on improving students' writing abilities. This strategy not only helps narrow the ability gap between students but also promotes comprehensive student development, providing a beneficial reference for the reform of Chinese writing instruction in primary and secondary schools in our country.

Table 1 Quantitative Evaluation Table for Personalized Writing Instruction Strategies

Evaluation Dimension	Specific Metric	Experimental Group (Personalized Instruction)	Control Group (Traditional Instruction)	Gain Comparison & Interpretation
Overall Writing Ability	Pre-test Average Score	58.2	55.1	Comparable initial proficiency
	Post-test Average Score	72.6	60.3	Significant improvement in Experimental Group
	Improvement Magnitude	+14.4 points	+5.2 points	Exp. Group gain is 2.77x that of Control Group
	Delayed Post-test Average Score*	70.5*	58.1*	Persistence of Effect: Exp. Group retained gains much better, with lower score decay.
Sub-skill Improvement (Post-test Score Rate)	Lexical Resource	75%*	62%*	Exp. Group showed notable progress in vocabulary richness & accuracy.
	Sentence Structure	78%*	58%*	Exp. Group used complex sentences and rhetorical devices more proficiently.
	Text Organization & Coherence	80%*	55%*	Exp. Group's greatest advantage was in logical flow and structural integrity.
Gain by Student Proficiency Level	Low-Proficiency Students	Improvement: +18.5*	Improvement: +6.0*	Largest Gain: Primarily seen in >40% reduction* in grammar/spelling errors.
	Mid-Proficiency Students	Improvement: +14.0*	Improvement: +5.5*	Balanced development across all sub-skills.
	High-Proficiency Students	Improvement: +12.0*	Improvement: +4.0*	Qualitative Leap: Notable progress in argument depth and expressive innovation.
Teaching Tools & Efficacy	Usage Rate: Mind Mapping*	95%*	30%*	Led to >25% improvement in logicality and completeness of essays in Exp. Group.
	Usage Rate: Real-time Grammar/Style Feedback*	90%*	10%*	Enabled >60% immediate error correction* during the drafting phase for Exp. Group.
	Usage Rate: Multi-dimensional Feedback Reports*	85%*	15%*	Significantly deepened Exp. Group's understanding of writing conventions.

6.2 Qualitative Analysis of Core Competency Development

Through classroom observations regarding the enhancement of students' metacognitive abilities during the writing process, as well as interview coding analysis concerning changes in learning motivation, this study reveals the positive impact of data-driven personalized writing instruction on the development of students' core competencies. In terms of metacognitive improvement, observation records indicate that students demonstrate more active self-monitoring and adjustment when utilizing personalized writing strategies. For instance, during the ideation phase, students utilized mind mapping tools to visualize content structure, effectively identifying and correcting deficiencies in their thought processes, thereby improving the coherence and logic of their writing. Interview coding results show that students exhibit higher learning motivation within the personalized writing instruction environment. This elevation in motivation stems not only from the improvement of writing skills themselves but also from the enhancement of self-efficacy and a sense of achievement during the writing process. Students reported that through real-time feedback and personalized

suggestions, they could more clearly recognize their own learning needs, allowing for more targeted learning activities. Furthermore, students' capacities for self-reflection and self-adjustment during the writing process were strengthened. Data indicates that the frequency of revisions in the experimental group was significantly higher than in the control group, and the distribution of error types showed a decreasing trend. This suggests that with the support of personalized writing instruction, students are able to more proactively discover and correct errors, promoting the iterative enhancement of writing abilities. As a critical component of social constructivist pedagogical strategies, peer assessment also demonstrated positive effects in this study. The increased frequency of interaction among students, improved quality of peer reviews, and enhanced social network density all indicate that students formed a robust learning community during the writing process, which facilitates the collective improvement of writing standards. However, qualitative analysis also found that the development of core competencies is a complex process influenced by multiple factors, such as individual differences among students, teachers' instructional styles, and school teaching resources. Therefore, when implementing personalized writing instruction, these factors must be considered to adapt to the needs of different students. In summary, data-driven personalized writing instruction aids in enhancing students' core competencies, particularly metacognitive abilities and learning motivation; however, educational practice must also pay attention to individual differences and flexibly adjust teaching strategies to achieve the comprehensive development of core competencies.

6.3 Assessment of Tool Usage Efficacy

The assessment of the efficacy of AI grading systems in writing instruction hinges critically on their accuracy and efficiency. Research indicates that AI grading systems demonstrate high accuracy in grammar correction and stylistic suggestions; consistency analysis results with manual re-verification show that the two achieve a high rate of agreement in most cases. For example, in one experiment, the grammar correction accuracy of the AI grading system reached 92%, compared to 95% in the manually verified sample, indicating that AI grading systems possess high credibility in grammar correction. As an important link in writing instruction, the quality of peer assessment directly affects students' learning outcomes. In a digital environment, the correlation between the quality of peer assessment and social network density has become a new dimension for evaluating tool efficacy. Statistical analysis shows that in learning communities with high social network density, the quality of peer assessment is higher, and interaction among students is more frequent, which may be related to the volume of information exchange and reciprocity brought about by high social network density. For instance, in a study targeting high school students, classes with higher social network density saw a 17% increase in the effectiveness of peer assessment, and the magnitude of writing ability improvement was significantly higher than in other classes. Furthermore, the convenience and ease of use of tools are also important indicators for evaluating efficacy. In practical application, the acceptance of tools by teachers and students directly influences their usage frequency and effect. A survey of teachers revealed that over 80% believe that AI grading systems which are easy to operate and provide fast feedback can effectively improve the efficiency of writing instruction. Meanwhile, student feedback indicates that writing tools with interactive suggestions and immediate feedback help them identify and correct errors more quickly, thereby improving writing ability. However, the assessment of tool usage efficacy should not be limited to technical and functional levels but should also consider the long-term impact on the learning process and outcomes. For example, long-term reliance on AI grading systems may affect students' self-correction abilities, a concern that has been confirmed in certain studies. Therefore, when evaluating tool efficacy, it is necessary to comprehensively consider support for the learning process as well as the long-term impact on the learner's capability development. In conclusion, the efficacy assessment of AI grading systems and peer assessment tools should be comprehensively considered based on multiple dimensions, including accuracy, social network density, ease of use, and long-term impacts on the learning process and outcomes. Such an evaluation system can more comprehensively reflect the practical application value of tools in instruction, providing a basis for subsequent adjustments in teaching strategies and tool optimization.

7 DISCUSSION AND REFLECTION

7.1 Effectiveness Boundary of the Strategy Model

In the process of exploring the application of the personalized writing learning strategy model, determining the boundary of its effectiveness is key to evaluating its practical success. Research indicates that the level of regional digital infrastructure has a non-negligible impact on the implementation effects of the strategy model. Regions with higher levels of digital infrastructure experience rapid advancement in educational informatization, providing robust hardware support and technical assurance for the implementation of the strategy model. Firstly, in regions with advanced digital infrastructure, schools typically possess complete network facilities and high-speed computing capabilities, enabling the personalized writing instruction strategy model to run efficiently. For example, digital tools such as real-time grammar detection and style adaptation suggestions require strong data processing capabilities to ensure their accuracy and immediacy. Statistics show that students in these regions demonstrate more significant gains in writing ability improvement, which is likely directly related to the efficiency of technical support. However, in regions with lower levels of digital infrastructure, the implementation effect of the strategy model is constrained. Issues such as unstable networks and insufficient hardware equipment obstruct the application of personalized tools. In these regions, interaction between teachers and students may still rely on traditional teaching methods, preventing the full

realization of the strategy model's advantages. Furthermore, economic disparities between regions lead to uneven allocation of educational resources, which also affects the effectiveness boundary of the strategy model. In resource-rich areas, teachers and students can fully utilize various digital tools, whereas in resource-poor areas, teachers may lack necessary technical training, and students may struggle to participate in personalized learning due to a lack of devices. When considering effectiveness boundaries, attention must also be paid to differences in grade-level adaptability. For instance, the writing of elementary narrative essays differs significantly in difficulty and requirements from high school argumentative essays; the strategy model requires corresponding adjustments when addressing different grade levels. The elementary stage may focus more on stimulating students' imagination and creativity, while the high school stage emphasizes the cultivation of logical thinking and argumentation skills. Finally, the balance between technical ethics and pedagogical subjectivity cannot be ignored. Controversies regarding data privacy protection and algorithm transparency may affect the application and promotion of the strategy model. Simultaneously, the teacher's role is transforming from a knowledge transmitter to a learning designer, a shift that requires teachers to possess corresponding information literacy and pedagogical innovation capabilities. In summary, the effectiveness boundary of the strategy model is influenced by multiple factors, including regional digital infrastructure levels, economic disparities, grade-level adaptability, and technical ethics. When promoting the strategy model, these factors should be fully considered, and targeted implementation strategies should be formulated to achieve educational equity and the improvement of teaching quality.

7.2 Balance Between Technical Ethics and Pedagogical Subjectivity

Against the backdrop of digital transformation in education, the balance between technical ethics and pedagogical subjectivity has become a focal point in the field of education. The intervention of technology has not only changed traditional teaching models but also imposed new requirements on the role of teachers. The teacher's role is transitioning from a knowledge transmitter to a learning designer, a shift that challenges teacher subjectivity. First, data privacy protection has become an important issue in technical ethics. In personalized writing instruction, the collection and analysis of student data is an indispensable link. However, ensuring that students' data privacy is not violated is a matter that must be treated seriously. Research indicates that students possess a high degree of sensitivity and awareness regarding the protection of their personal data; therefore, data processing during instruction must strictly comply with relevant laws and regulations and obtain student consent. Second, algorithm transparency is another focus of controversy in technical ethics. The decision-making processes of AI grading systems used in personalized writing instruction are often opaque. This may affect the trust teachers and students place in evaluation results. Therefore, improving algorithm transparency and allowing teachers and students to understand the standards and basis of evaluation are key to guaranteeing the fairness of assessment. Furthermore, teacher subjectivity faces repositioning in a technology-intervened educational environment. The use of technology should not weaken the dominant role of the teacher but should serve as an auxiliary tool to enhance instructional effectiveness. The teacher's role in the classroom is gradually shifting from a transmitter of knowledge to a guide and designer of the learning process. This transformation requires teachers to possess the ability to design and adjust teaching strategies while mastering technology. In this process, the professional development of teachers appears particularly important. Teachers need to enhance their own information technology literacy and the ability to combine technology with teaching practice through continuous learning and training. Statistics show that teachers who have undergone professional training see more significant improvements in their students' writing abilities when implementing personalized teaching strategies. Finally, the balance between technical ethics and pedagogical subjectivity also involves the issue of educational equity. The introduction of technology may exacerbate the uneven distribution of educational resources, especially where there are differences in regional digital infrastructure levels. Therefore, policymakers need to focus on the popularization and fairness of technology, ensuring that all students can enjoy the convenience brought by digital education. In summary, the balance between technical ethics and pedagogical subjectivity is a complex and subtle issue, requiring educators to think deeply about how to make appropriate decisions and adjustments regarding protecting student privacy, ensuring algorithm transparency, maintaining teacher subjectivity, and promoting educational equity while driving the development of educational technology.

7.3 Expansion of Future Research Directions

With the establishment of the current personalized writing instruction strategy model and the deepening of empirical research, future studies can further expand into the conceptual development of multimodal writing support systems. Such systems would combine technologies like voice recognition and natural language processing to achieve real-time monitoring and guidance of the student's writing process. For example, through voice input technology, students can more conveniently record their thoughts, improving writing efficiency; meanwhile, natural language processing technology can analyze language expression in students' writing in real-time, providing personalized suggestions on grammar, vocabulary, and sentence structures. In addition, future research can explore the possibilities of interdisciplinary migration applications. Writing is not only a core component of language learning but also an indispensable skill in the learning processes of other disciplines such as history and science. Applying personalized writing instruction strategies to different disciplinary fields helps enhance students' comprehensive literacy. For instance, in history, students can better analyze historical events and understand historical figures through personalized writing

support systems, accurately expressing their viewpoints in writing. Regarding the balance between technical ethics and pedagogical subjectivity, future research needs to focus on controversies surrounding data privacy protection and algorithm transparency. As the volume of student data collected by personalized writing instruction systems grows, ensuring the secure and compliant use of this data, as well as the fairness of algorithmic decision-making, will be important topics for future research. At the same time, research must also pay attention to the transformation of the teacher's role in the personalized teaching process, shifting from knowledge transmitter to learning designer, to better adapt to the digital teaching environment. In terms of implementation paths, future research can focus on the following aspects: 1. Develop personalized writing instruction systems suitable for different grade levels and regions to meet the needs of diverse student groups. For example, designing corresponding teaching strategies and tools based on the different characteristics of elementary school narrative writing versus high school argumentative writing. 2.Explore allocation standards for digital teaching resources to provide hardware and software support for personalized writing instruction. This includes but is not limited to intelligent writing assistance tools and cloud-based learning platforms. 3.Construct a training curriculum system for teacher information literacy to help teachers adapt to the digital teaching environment and master personalized teaching strategies. Furthermore, attention should be paid to teachers' professional growth, providing them with continuous learning and training opportunities. 4.Through in-depth research on learning motivation, metacognitive abilities, and other aspects, explore the impact of personalized writing instruction on the development of students' core competencies. This will help perfect the theoretical system of personalized writing instruction and provide more powerful support for practice. In conclusion, the expansion of future research directions will revolve around the development of multimodal writing support systems, interdisciplinary migration applications, and the balance between technical ethics and pedagogical subjectivity. These studies will further promote the deep development of personalized writing instruction, offering strong support for improving students' writing abilities and core competencies.

8 CONCLUSION AND SUGGESTIONS

8.1 Summary of Theoretical Contributions

This study has achieved a breakthrough in the operational definition of personalized learning strategies. By deeply analyzing existing personalized learning theories and combining them with the characteristics of writing instruction, a student-centered four-dimensional driving structure (Diagnosis/Intervention/Feedback/Assessment) was proposed, providing a clear operational path for the digital transformation of writing instruction. This strategy model combines diagnosis with intervention and emphasizes the importance of real-time feedback and assessment, thereby achieving personalized support throughout the entire writing instruction process. Regarding paradigm innovation in the digital transformation of writing instruction, this study constructed a digital tool functional mapping system, integrating multi-functional modules such as mind mapping tools, intelligent material recommendation, real-time grammar detection, and stylistic adaptation suggestions with various stages of writing instruction. This integration not only improves the efficiency of writing instruction but also promotes the enhancement of students' writing abilities through a dynamic regulation mechanism where data flows throughout the writing process. Furthermore, this study designed a support architecture for core competency development, proposing data-based representation indicators for language construction ability and a dynamic monitoring dimension design for cognitive development levels. This architecture provides dual support—quantitative and qualitative—for assessing and promoting the development of students' core competencies during the writing process. Statistics show that the experimental group significantly outperformed the control group in terms of writing ability improvement, proving the effectiveness of the personalized learning strategy. Simultaneously, improvements in metacognitive abilities and changes in learning motivation were confirmed in classroom observations and student interviews, further verifying the validity of the strategy model proposed in this study. In terms of the balance between technical ethics and pedagogical subjectivity, this study fully considered controversies regarding data privacy protection and algorithm transparency, proposing a pathway for the transformation of the teacher's role from knowledge transmitter to learning designer. This not only provides new career development opportunities for teachers but also ensures humanistic care and technical ethics within the teaching process. In summary, the theoretical contribution of this study lies in proposing an operational definition of personalized learning strategies, constructing a paradigm for the digital transformation of writing instruction, and designing a support architecture for core competency development, providing theoretical and practical guidance for the future development of writing instruction.

8.2 Suggestions for Practical Promotion

The design of a flexible framework for school-based strategy adjustment aims to ensure that personalized writing instruction strategies can adapt to the educational resources and student needs of different schools. Specifically, the following implementation plans and adjustment strategies are available for reference: First, schools should establish regional teaching research communities to share high-quality digital teaching resources through inter-school cooperation, promoting the exchange and dissemination of teaching experiences. Teaching research communities can regularly organize teachers to participate in professional training to enhance their information technology capabilities and instructional innovation abilities. Additionally, a resource-sharing platform can be established within the community to integrate various digital teaching tools and materials to meet the needs of personalized instruction.

Second, schools need to design a school-based flexible framework that allows teachers to flexibly adjust teaching strategies based on students' actual levels and the school's specific conditions. This framework should include the following core elements: first, clear teaching objectives and core competency cultivation indicators; second, diverse instructional activity designs to meet different students' learning styles and ability needs; third, continuous teaching assessment and feedback mechanisms to monitor teaching effectiveness and student progress. Furthermore, schools should encourage teachers to use data-driven methods to optimize instructional decisions. By collecting and analyzing student learning data, teachers can more accurately identify students' weak points and provide targeted tutoring. At the same time, schools should support teachers in conducting action research, encouraging them to constantly try and improve teaching strategies in practice. In addition, schools must also pay attention to technical ethics issues, ensuring that the application of digital teaching tools does not infringe on student privacy, while also guaranteeing the transparency and fairness of algorithms. When using digital tools, teachers should fully consider students' personal rights and interests, ensuring that the application of technology truly serves students' learning and growth. Statistics show that schools adopting the above strategies have achieved significant results in improving students' writing abilities. For instance, after implementing school-based strategies, the magnitude of improvement in student writing abilities at a certain school significantly exceeded that of schools not adopting such strategies. This indicates that the application of a flexible framework design for school-based strategy adjustment is feasible and effective in practice. In summary, when promoting personalized writing instruction strategies, schools should attach importance to the construction of regional teaching research communities, design school-based flexible frameworks, and focus on technical ethics issues to achieve the optimal allocation of teaching resources and the comprehensive development of students' core competencies.

8.3 Reference for Policy Formulation

In the current context of the digital transformation of education, policymakers face challenges regarding how to rationally allocate digital teaching resources and how to reconstruct the curriculum system for teacher information literacy training. The following suggestions aim to provide references for policy formulation: First, recommendations for digital teaching resource allocation standards are crucial. Policies should ensure the equitable distribution of resources to narrow the digital divide between urban and rural areas and between regions. Research shows that the use of high-quality digital resources can significantly improve students' learning efficiency. Therefore, it is suggested to establish the following standards: first, rationally allocate digital teaching equipment based on student numbers and disciplinary needs; second, prioritize investment in interactive and intelligent teaching platforms to support personalized learning; third, regularly update resource libraries to ensure teaching content keeps pace with the times. Second, the reconstruction of the teacher information literacy training curriculum system is key to improving teaching quality. Currently, many teachers face obstacles in using digital teaching tools, which affects teaching effectiveness. Therefore, it is suggested to take the following measures: first, build a layered, modular training system to meet the needs of teachers of different age groups and disciplinary backgrounds; second, combine theory with practice, enhancing teachers' practical operational capabilities through case analysis and simulated teaching; third, strengthen tracking and assessment after training to ensure the sustainability of training effects. In addition, the following two points should also be included in policy formulation considerations: first, establish a digital teaching resource assessment mechanism to regularly audit resource quality, ensuring applicability and effectiveness. Statistics show that low-quality digital resources not only fail to improve teaching effectiveness but may also cause a waste of teaching resources. Second, encourage teachers to participate in the development of digital teaching resources, enhancing their innovation capabilities and resource integration abilities. Through policy incentives, guide teachers to integrate personalized teaching concepts into resource development, forming digital teaching resource libraries with school-based characteristics. In summary, policy formulation should focus on the rational allocation of digital teaching resources and the enhancement of teacher information literacy, thereby promoting the comprehensive improvement of educational quality.

COMPETING INTERESTS

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

REFERENCES

[1] Qiu Feifei. An Exploration of Primary School Chinese Language Teaching Strategies in a Digital Environment. Primary and Secondary School Educational Technology, 2023(12): 51-53.
[2] Zhang Ping. The Practice of Intelligent Evaluation of Primary School Chinese Writing Supported by "Smart Paper and Pen". Shanghai Education, 2023(34): 51.
[3] Sun Fei. Improving the quality of composition teaching with digital and diversified teaching methods. Chinese Character Culture, 2022(02): 50-51.
[4] Zhao Changling. Junior High School Chinese Writing Teaching Supported by Digital Tools. Middle School Chinese, 2024(05): 78-80.
[5] Liu Bangqi. Smart classrooms lead the digital transformation of teaching: trends, characteristics and practical strategies. Research on Educational Technology, 2023, 44(08): 71-79.

[6] Ma Jianfei, Liang Yu, Wu Yinghui, et al. 70 Years of Development of International Chinese Language Education Resources: Achievements and Prospects. Journal of Tianjin Normal University (Social Sciences Edition), 2021(6): 15-22.

[7] Wu Jin. A Study on High School Practical Writing Teaching from the Perspective of Communicative Context Writing. Yinchuan: Ningxia University, 2021.

[8] Jiao Jianli. ChatGPT: Friend or Enemy of School Education?. Modern Educational Technology, 2023, 33(04): 5-11.

[9] Wang Peinan. The Rise of AI Writing and Algorithm Literacy Education — A Case Study of ChatGPT. Youth Journalist, 2023(03): 94-96.

[10] Zhou Jianqiong. The Dissolution and Reconstruction of Author Subjectivity in the Context of Artificial Intelligence Writing—Taking Chen Qiufan's Human-Computer Interaction Writing Experiment as the Center. Contemporary Literature, 2021(04): 145-150.

[11] Wu D, Li H, Chen X. An Analysis of the Impact of General-Purpose Large Models for Artificial Intelligence on Education. Open Education Research, 2023(02): 19-25+45.

[12] Shen Shusheng, Zhu Zhiting. ChatGPT-type products: their intrinsic mechanisms and their impact on learning evaluation. China Distance Education, 2023(04): 8-15.

[13] Wu Yonghe, Xu Qiuxuan, Yan Huan, et al. Digitalization empowers the openness, inclusiveness and high-quality development of future education. Open Education Research, 2023, 29(03): 104-113.

[14] Xu Juan, Ma Ruiling. Digital transformation empowers the high-quality development of international Chinese education. Electrified Education Research, 2023, 44(10): 121-128.

[15] Xiao Wen. Empowering the high-quality development of Chaoyang education with digital education. Primary and Secondary School Information Technology Education, 2024(Z1): 27.

[16] Zheng Zhihong. Technological evolution and implementation path of digital transformation empowering the transformation of teaching models. China Educational Informatization, 2024, 30(11): 103-111.

[17] Shen Ling, Dou Zhenglin, Tang Dingyong. A Study on the Practice of Online Classroom in Secondary Vocational Schools under the Background of Digital Transformation: The Construction Model of Online Classroom for the Entire School of Dingyuan Chemical School. Anhui Educational Research, 2023(33): 103-105.

PERSPECTIVES OF CHINESE EFL UNIVERSITY STUDENTS ON USING REDNOTE FOR AUTONOMOUS ENGLISH LISTENING LEARNING

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Abstract: This study investigates how Chinese university students perceive the use of Rednote as a tool for autonomous English listening learning. Although English listening development relies on sustained exposure to meaningful input, classroom-based practice in Chinese universities is often constrained by limited hours and exam-oriented instruction. Social media platforms have therefore become an important supplementary channel for self-directed listening. Rednote, with its short videos, creator-led explanations, and personalised recommendation system, offers easily accessible listening materials, yet its entertainment orientation and uneven content quality may also pose challenges. A mixed-methods questionnaire was administered to 120 university students who had prior experience using Rednote for listening practice. Quantitative results consistently show positive attitudes, with students reporting increased motivation, greater confidence, reduced anxiety, and a stronger willingness to engage in listening beyond the classroom. Participants also recognise practical benefits such as flexible access, diverse resources, and improved autonomy. However, they note several limitations, including distractions from entertainment content, the fragmentation of short-video input, and the need to evaluate the reliability of user-generated posts. Qualitative responses further illustrate these tensions, highlighting how learners balance Rednote's convenience with the effort required for self-regulation. Overall, the findings provide a focused account of Chinese EFL university students' perspectives on using Rednote to support autonomous English listening learning.
Keywords: Rednote; Autonomous English listening; EFL learners; Social media learning; Learner perceptions

1 INTRODUCTION

1.1 Background

English listening is a demanding skill for many learners of English as a Foreign Language (EFL) because improvement depends on frequent exposure to meaningful and comprehensible spoken input [1]. In Chinese university classrooms, however, listening practice is often limited by restricted contact hours, exam-oriented pacing, and teacher-selected materials, which frequently position students as passive receivers rather than active listeners [2]. As a result, EFL learners commonly seek extra input beyond class to strengthen comprehension, notice spoken vocabulary and expressions in context, and gradually adapt to natural speech rates and accent variation. This need makes autonomous listening practice an important complement to formal instruction.

Against this background, social media has become a common space for autonomous listening within Computer-Assisted Language Learning (CALL) and Mobile-Assisted Language Learning (MALL), and Rednote is a particularly relevant example for Chinese EFL university students [3]. Its short videos, creator-led explanations, and recommendation system can supply bite-sized listening input, study tips, and peer-shared resources that feel approachable and motivating. Students also value the sense of community, where commenting and saving posts help build a routine. At the same time, learners hold mixed attitudes because the platform brings constraints such as entertainment distractions, uneven content quality, limited sustained listening for academic purposes, and algorithm-driven information bubbles. These tensions make Rednote a valuable case for examining how students balance perceived benefits with perceived limitations in English listening practice.

1.2 Problem Statement

Existing studies on English learning supported by social media usually show that internet sites can increase access to input, interaction, and shared resources outside of lesson time and location [4]. However, when this work is considered in relation to perspectives of Chinese EFL university students on using Rednote for autonomous English listening learning, several apparent gaps remain. First, much of the literature still centres on earlier or more widely studied platforms such as blogs, Facebook, WeChat, or QQ, with limited attention to Rednote as a listening-learning environment [5]. Rednote's short-video design, creator-led explanations, and algorithmic feed may influence what learners hear, how long they stay engaged, and how they sequence listening practice, but these platform-specific features are rarely examined in listening research. Second, existing studies often emphasise advantages such as convenience, motivation, and flexible access, while giving less detailed treatment to constraints that shape real-world use [6]. For autonomous listening in particular, issues such as distraction, uneven content reliability, fragmented

exposure, and limited depth for sustained academic listening need closer investigation. This study, therefore, aims to examine how Chinese university students perceive Rednote for autonomous English listening, focusing on their attitudes toward the platform, how they interpret its advantages, navigate its constraints, and manage their own learning.

1.3 Research Objectives

This study investigates the attitudes of Chinese EFL university students towards using Rednote as a social media platform for autonomous English listening learning. It also explores their perceived benefits and limitations when using Rednote to support listening development.

1.4 Research Questions

RQ1: What attitudes do Chinese EFL university students hold towards using Rednote for autonomous English listening learning?
RQ2: What benefits and limitations do Chinese EFL university students perceive when using Rednote to support autonomous English listening learning?

2 LITERATURE REVIEW

2.1 Theoretical Foundations

According to constructivist learning theory, which is associated with Jean Piaget, learning is an active process whereby individuals construct knowledge by connecting new information to existing cognitive schemas [7]. From this perspective, autonomous English listening on Rednote is not merely exposure to audio input, but rather an activity that involves creating meaning. Students select videos that match their interests and level, interpreting spoken messages through their prior knowledge and understanding. They gradually refine their listening skills through repetition, observation, and reflection. Over time, their understanding of pronunciation, vocabulary in context, and discourse patterns adjusts as they integrate new input and reorganise their existing knowledge. This aligns with the constructivist emphasis on learner agency and self-directed learning.

This study is further supported by an interaction-based view, drawing on Michael Long's Interaction Hypothesis and Lev Vygotsky's sociocultural theory, including the Zone of Proximal Development (ZPD) [8-9]. These perspectives emphasise that listening skills are developed when learners engage with others and with tools that provide support, feedback, and manageable challenges. On Rednote, captions, short explainer videos, and creator demonstrations can provide scaffolding, while comments, replies, and sharing offer light-touch opportunities for clarification, confirmation, and exposure to alternative interpretations. Together, these theories justify the examination of how Rednote enables self-managed listening routines, and of how learners evaluate its benefits and limitations in practice.

2.2 Social Media in Autonomous English Listening Learning

Work on CALL can be traced back to drill-based programs in the 1960s and 1970s, and later expanded alongside the emergence of microcomputers in the 1980s and the development of networked, web-based learning in the 1990s. As mobile devices became widespread in the mid-2000s onward, MALL strengthened the shift toward learner-centred practice by enabling flexible access, personalised pacing, and lightweight interaction beyond scheduled class time. Within this broader move, social media has increasingly been discussed as an extension of CALL and MALL, not as a formal course space but as a convenient channel for exposure, sharing, and peer-supported learning routines [1]. For autonomous English listening learning, these developments are significant because improvement typically depends on sustained exposure to comprehensible spoken input.

Recent studies highlight that social media platforms can provide learners with authentic audio-visual materials, diverse accents, and informal communicative contexts that are less accessible in traditional classrooms [10]. Short-video applications, in particular, offer easily digestible listening segments that allow students to engage in frequent, low-pressure practice. Algorithms, tagging systems, and comment functions can further help users curate content, follow topics of interest, and observe peer explanations. At the same time, studies note concerns about distraction, uneven content quality, and the fragmented nature of brief clips, all of which may limit deeper comprehension. These mixed observations underline the need to understand how learners themselves navigate social media when managing autonomous English listening tasks.

2.3 Chinese University Students' Use of Rednote for English Listening

Rednote has become an increasingly common social media platform through which Chinese university students access English-related content [6]. Its blend of image-text posts and short videos allows learners to engage with vocabulary explanations, everyday expressions, exam tips, and situational language in a quick and accessible manner. English content creators on the platform include bilingual Chinese bloggers, language-training instructors, overseas students, and some native speakers, who often present materials through scene-based demonstrations, etymological breakdowns,

or contextualised examples. These features make Rednote a convenient space for fragmented and self-directed listening practice, offering exposure to varied accents, communicative styles, and authentic language use.

At the same time, the learning environment on Rednote reflects several platform-specific constraints [11]. Because content creation is largely unregulated, learners must navigate posts of varying quality and exercise caution when encountering inaccurate explanations or oversimplified teaching. The entertainment-driven recommendation system may also distract users or interrupt the continuity of listening practice, limiting deeper engagement with extended spoken input. Additionally, some creators promote commercial products or paid courses, requiring learners to assess the credibility and relevance of the content. Overall, Rednote offers Chinese university students flexible and appealing listening resources; however, its informal nature raises concerns about content reliability, sustained learning, and self-regulation that warrant further investigation.

2.4 Students Attitudes toward Rednote for EFL Listening Learning

Studies on learner attitudes in CALL and mobile language learning consistently show that positive perceptions strongly influence whether students adopt digital tools for listening practice. Studies have reported that social platforms offering authentic input, multimodal explanations, and flexible access often lead to greater motivation, confidence, and willingness to engage with listening tasks [12]. Within social media–supported environments, learners tend to value resources that reduce anxiety, provide relatable content, and allow for repeated exposure without the pressure of a classroom setting. These patterns help explain university students' favourable attitudes toward Rednote as an autonomous listening tool. Existing literature notes that short-form videos and creator-guided explanations can make listening activities feel more approachable, which aligns with students' reports of finding Rednote engaging and enjoyable. Research also indicates that learning spaces perceived as informal or student-centred can enhance confidence in handling challenging skills. This echoes learners' views that Rednote boosts confidence and sustains motivation for listening practice. Studies further highlight that platforms enabling quick, low-stakes practice often reduce avoidance behaviours. This supports students' responses that Rednote lessens reluctance toward listening tasks and promotes a more positive general attitude. Although entertainment-oriented platforms may not always be regarded primarily as educational tools, past work shows that learners frequently continue using them when they believe the benefits outweigh such limitations, consistent with students' intention to keep practising listening on Rednote.

Overall, the literature suggests that students' positive attitudes toward Rednote reflect broader trends in how social platforms shape engagement, affective responses, and autonomous listening behaviours.

2.5 Perceived Benefits and Limitations of Using Rednote for EFL Listening Learning

Social media has become an important channel for enriching EFL listening because it provides flexible access to diverse linguistic input and creates informal opportunities for practice [13]. Its multimodal features, such as images, captions, and short videos, make listening activities more engaging and comprehensible. At the same time, the constant flow of updated content exposes learners to everyday expressions and culturally situated communication. These characteristics help learners expand vocabulary, sustain motivation, and develop more autonomous listening habits. As a social media platform, Rednote shares these advantages. Its visually appealing posts, scenario-based explanations, and creator-generated short videos offer accessible listening materials that are closer to real-life language use. Interaction in the comment sections also fosters light peer support, enabling learners to clarify their doubts or observe others' learning strategies [6].

However, Rednote also presents notable limitations [11]. The quality of user-generated content varies, and some creators lack professional training, which raises concerns about the accuracy of their language input. The platform's strong entertainment orientation can distract learners and reduce their sustained engagement with listening tasks. Moreover, fragmented and unsystematic posts may not align with curriculum goals, requiring learners to invest additional effort in selecting reliable content and organising what they learn. These factors suggest that although Rednote offers valuable listening resources, its effectiveness depends on learners' digital literacy, self-regulation, and ability to identify trustworthy creators.

2.6 Research Gaps

Although social media has increasingly been recognised as a space for EFL listening practice, little is known about how learners engage with Rednote as a platform for autonomous listening [14]. Existing studies broadly examine more established applications such as WeChat, QQ, or Facebook, leaving Rednote's short-video structure and creator-driven explanations insufficiently explored. Moreover, prior research tends to emphasise general benefits of social-media learning without detailing how students handle distractions, evaluate the reliability of user-generated content, or cope with fragmented listening input [15]. Crucially, few studies investigate how Chinese university students self-regulate their listening on Rednote or how they weigh its perceived advantages against its limitations. This gap highlights the need for research that captures learners' specific practices and perspectives within Rednote's unique social media environment.

3 METHODOLOGY

3.1 Participants

A total of 120 Chinese university students were recruited through a public call for participation posted on Rednote. The group consisted of 56 males and 64 females, all between 18 and 25 years of age. Each participant had previous experience using Rednote to support autonomous English listening practice and regularly engaged in English learning at the tertiary level. The final sample, therefore, represented active EFL learners who had already incorporated Rednote into their personal listening routines, making them suitable for examining perceptions of this platform in self-managed listening development.

3.2 Instruments and Methods

The study employed a questionnaire containing both closed-ended and open-ended items to investigate students' perceptions of using Rednote for autonomous English listening. The instrument consisted of three sections. The first section gathered basic demographic information. The second section included a series of closed-ended statements designed to measure students' attitudes toward Rednote as well as their perceived benefits and limitations when using the platform for English listening practice. The third section invited participants to respond to open-ended questions, allowing them to elaborate on their experiences and provide additional insights beyond the structured items.
A five-point Likert scale (1 = strongly disagree, 5 = strongly agree) was used in the closed-ended section to collect quantitative data. Several items were adapted from the attitude scale used in the present study, which is adapted from established instruments in CALL research to enhance construct validity for the attitude component [12]. Reliability analysis using Cronbach's Alpha produced a coefficient of 0.79, indicating strong internal consistency across the scale. To obtain qualitative data, two open-ended prompts asked students to describe the advantages and challenges they encountered while using Rednote for English listening. Prior to full administration, a pilot test involving five students was conducted to refine item clarity and ensure the overall suitability and reliability of the questionnaire.

3.3 Data Collection

Data were collected through an online questionnaire administered after participants confirmed that they had used Rednote for autonomous English listening. The questionnaire link was distributed through Rednote, allowing students to complete it at their convenience. To ensure full comprehension of all items, the survey was provided in both Chinese and English. Participants first read a brief introduction outlining the purpose of the study and the voluntary nature of their participation. They then completed the demographic section, attitude scale, and items concerning perceived benefits and limitations of using Rednote for English listening. Responses were submitted anonymously to encourage honest reporting. The data were automatically recorded in a secure online database and later exported for quantitative and qualitative analysis.

3.4 Data Analysis

Quantitative responses were analysed using SPSS. Descriptive statistics, including means (M) and standard deviations (SD), were calculated to summarise students' attitudes toward using Rednote for autonomous English listening. These results were used to address the study's research objectives and research questions. For qualitative data, a content analysis approach was employed. Students' written comments on the perceived benefits and limitations of Rednote were examined through systematic coding and categorisation to identify recurring ideas and patterns. The combination of numerical trends and thematic patterns allowed for a more comprehensive interpretation of participants' perceptions.

4 RESULTS AND DISCUSSION

4.1 Chinese University Students' Attitudes toward Using Rednote for Autonomous English Listening Learning

To understand Chinese university students' attitudes toward using Rednote for autonomous English listening, participants rated eight statements on a five-point Likert scale. As shown in Table 1, all mean scores fall between 3.78 and 3.88, indicating generally positive perceptions of Rednote as a listening support tool. The overall mean of 3.83 (SD = 0.76) suggests that students consistently view the platform as a helpful complement to their listening practice. Students express the strongest agreement with Rednote's ability to enhance listening motivation (M = 3.88, SD = 0.74) and strengthen confidence in handling English listening tasks (M = 3.87, SD = 0.73). These two aspects appear central to learners' positive engagement, reflecting the motivational benefits frequently associated with social media–based learning environments. Listening through Rednote is also regarded as enjoyable and engaging (M = 3.85, SD = 0.86), which supports the idea that multimodal and creator-driven content can reduce the perceived difficulty of listening activities. Reduced anxiety is another notable perception (M = 3.83, SD = 0.75). Learners experience less pressure when practising listening in informal, familiar online spaces. Similarly, many believe that Rednote helps them maintain a more positive attitude toward English listening overall (M = 3.80, SD = 0.72). A parallel trend emerges in responses, suggesting that Rednote reduces reluctance to study and participate in listening tasks (M = 3.79, SD = 0.77), indicating that the platform may help students overcome avoidance tendencies commonly observed in challenging skill areas, such as listening. Students also report an intention to continue using Rednote for future listening practice (M = 3.84, SD =

0.71), implying sustained acceptance of the platform. The comparatively lower, though still positive, agreement with using Rednote specifically for educational purposes (M = 3.78, SD = 0.81) may relate to its entertainment-oriented design, which can blur the boundary between leisure and learning. Overall, these patterns echo previous findings that social media environments can enhance motivation, confidence, and engagement in EFL learning [12]. The results indicate that Rednote, despite its informal nature, provides a supportive space where students feel more confident, motivated, and willing to engage in autonomous English listening. Incorporating such platforms into listening-learning routines may therefore enrich learners' exposure and promote more sustained participation.

Table 1 Means and Standard Deviations of Chinese University Students' Attitudes Toward Using Rednote for Autonomous English Listening

Items	N	M	SD
You prefer to use Rednote for educational purposes.	120	3.78	0.81
Listening through Rednote is enjoyable and engaging.	120	3.85	0.86
Using Rednote boosts your confidence in English listening.	120	3.87	0.73
Rednote increases your motivation for English listening learning.	120	3.88	0.74
Rednote reduces your anxiety about English listening activities.	120	3.83	0.75
Rednote reduces your reluctance to study and participate in English listening learning.	120	3.79	0.77
Rednote helps improve your positive attitude toward English listening.	120	3.80	0.72
You intend to continue using Rednote for English listening in the future.	120	3.84	0.71
Average	120	3.83	0.76

Note: 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

4.2 Perceived Benefits and Limitations of Using Rednote for Autonomous English Listening

4.2.1 Analysis of the Quantitative Data
The responses in Table 2 indicate that students perceive clear advantages in using Rednote for autonomous English listening, with a high overall mean score (M = 3.85, SD = 0.76). The strongest agreement is evident in the view that regular use of Rednote improves listening skills (M = 3.88, SD = 0.74) and that the platform stimulates more active listening engagement than traditional classroom methods (M = 3.87, SD = 0.73). Students also report convenient access to listening materials at any time and place (M = 3.86, SD = 0.79), highlighting Rednote's flexibility. Access to a broad range of listening resources receives similarly positive evaluations (M = 3.84, SD = 0.75), suggesting that the platform effectively expands exposure beyond textbook input. In addition, students recognise that Rednote strengthens their ability to manage autonomous listening routines (M = 3.82, SD = 0.78), reflecting growing confidence in self-directed learning. Overall, the results suggest that Rednote promotes motivation, skill development, and learner independence, aligning with the view that social platforms can enhance language learning through accessible and varied input [6].

Table 2 Means and Standard Deviations for Benefits

Items	N	M	SD
You can access a wide range of English listening materials through Rednote.	120	3.84	0.75
Rednote encourages you to engage more actively in listening practice compared with traditional classroom methods.	120	3.87	0.73
Your English listening skills improve when using Rednote regularly.	120	3.88	0.74
Learning with Rednote strengthens your ability to manage autonomous English listening practice.	120	3.82	0.78
Rednote allows you to practise English listening conveniently at any time and in any place.	120	3.86	0.79
Average	120	3.85	0.76

Note: 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

The questionnaire also examined challenges students face when relying on Rednote for autonomous English listening. As shown in Table 3, the highest mean score indicates that students are concerned that entertainment-focused posts can easily divert attention from listening practice (M = 3.81, SD = 0.76). This is followed closely by the belief that the fragmented nature of short videos makes sustained listening difficult (M = 3.80, SD = 0.87), highlighting how platform design may hinder the deeper processing of spoken input. Learners also report that evaluating the trustworthiness of content creators requires considerable effort (M = 3.77, SD = 0.74), suggesting that inconsistent content quality remains

a significant barrier. Additionally, several students encounter inaccurate or unreliable listening materials (M = 3.73, SD = 0.75), which may erode confidence in using the platform for systematic listening development. Overall, these findings suggest that while Rednote offers accessible input, its informal and entertainment-driven environment presents challenges that students must navigate carefully to maintain effective learning [11].

Table 3 Means and Standard Deviations for Limitations

Items	N	M	SD
You sometimes encounter English listening content on Rednote that is inaccurate or unreliable.	120	3.73	0.75
You find that entertainment-oriented posts on Rednote can distract you from focused listening practice.	120	3.81	0.76
You feel that fragmented short videos on Rednote make it difficult to engage in sustained English listening.	120	3.80	0.87
You need extra effort to judge which Rednote creators provide trustworthy English listening materials.	120	3.77	0.74
Average	120	3.78	0.78

Note: 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

4.2.2 Analysis of the Qualitative Data

The two open-ended questions invited participants to elaborate on the benefits and barriers they experience when using Rednote for autonomous English listening. Their responses supplement the quantitative findings and reflect patterns highlighted in previous literature. In terms of benefits, many students noted that Rednote provides convenient access to varied listening input that goes beyond classroom materials. They emphasised that short videos, bilingual explanations, and scenario-based demonstrations help them understand spoken English more easily and make listening practice feel less rigid. Several participants also mentioned that the interactive comment sections allow them to observe peer questions or interpretations, which echoes sociocultural views that light forms of online interaction can support comprehension and confidence building. Students further appreciated that Rednote enables flexible learning schedules, allowing them to fit listening practice into daily routines. Regarding barriers, students reported concerns consistent with earlier research on social media learning environments. A recurring challenge was the uneven reliability of user-generated posts, particularly when creators lacked professional training. Some respondents explained that promotional or entertainment-driven content often appeared in their feed, disrupting concentration and reducing the continuity needed for deeper listening. Others expressed that fragmented short clips, although engaging, sometimes hindered their ability to follow longer or more academic listening tasks. A smaller number also mentioned the effort required to evaluate trustworthy creators and manage distractions. Overall, the qualitative data indicate that Rednote provides accessible and motivating listening opportunities; however, its value depends on learners' ability to select credible content and regulate their attention during autonomous study [15].

5 ETHICAL STATEMENT

All participants were recruited voluntarily through a Rednote announcement and provided informed consent prior to participating in the study. Participation was anonymous, and responses were used solely for research purposes in accordance with standard ethical guidelines.

6 CONCLUSION

The findings indicate that Chinese university students generally maintain a favourable view of using Rednote to support autonomous English listening learning. Regular engagement with the platform fosters greater confidence, stronger motivation, and a more positive attitude toward listening practice outside formal instruction. Rednote's accessible short videos, scenario-based explanations, and creator-generated content offer varied listening opportunities that make learning feel more approachable and relevant to everyday communication. These features appear to encourage students to practise more frequently and take greater initiative in managing their own listening routines. At the same time, the study highlights several practical concerns. Participants note that the mixed quality of user-generated posts, frequent entertainment-focused recommendations, and fragmented content structure may interfere with focused listening or deeper comprehension. Learners also recognise the need to evaluate the credibility of creators and manage potential distractions. Overall, Rednote serves as a useful supplementary tool for autonomous listening, provided that students employ careful selection and effective self-regulation.

6.1 Significance

This study provides a clear understanding of how Chinese university students perceive the use of Rednote for autonomous English listening. It expands the existing literature on social media-supported EFL learning by focusing on a platform that has received limited academic attention. The findings also provide practical insights for teachers and

content developers, showing how learners experience the advantages and challenges of Rednote and how such platforms may be incorporated into independent listening practices.

6.2 Limitations and Recommendations for Future Research

Although this study offers valuable insights into Chinese university students' perceptions of using Rednote for autonomous English listening, several limitations remain. The sample is limited to users already active on Rednote, which may not represent learners with different levels of digital access or varied social media habits. The study also focuses only on listening, leaving other language skills unexplored. Future research may broaden participant groups, compare different social platforms, or investigate how Rednote supports skills such as speaking, reading, and writing. Longitudinal studies could also examine how learners' perceptions and listening behaviours evolve.

COMPETING INTERESTS

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

REFERENCES

[1] Li Rui. Effects of mobile-assisted language learning on EFL learners' listening skill development. Educational Technology & Society, 2023, 26(2): 36-49.
[2] Zhao Jinman, Lee Chang In. Teaching EFLLs listening subskills with a speaking listening model in a computer mediated communication setting. Frontiers in Psychology, 2022, 13: 836013.
[3] Yang Xiaona. Construction of a blended teaching model for college English listening based on Chaoxing Learning Platform. Science and Education Guide, 2023(13): 119-121.
[4] Han Shujun. Flipped classroom: Challenges and benefits of using social media in English language teaching and learning. Frontiers in Psychology, 2022, 13: 996294.
[5] Istifci I, Ucar A D. A review of research on the use of social media in language teaching and learning. Journal of Educational Technology and Online Learning, 2021, 4(3): 475-488.
[6] Liu G L, Zhao X, Feng M T. TikTok refugees, digital migration, and the expanding affordances of Xiaohongshu (RedNote) for informal language learning. International Journal of TESOL Studies, 2025, 250123: 1-15.
[7] Nurhasnah N, Sepriyanti N, Kustati M. Learning theories according to constructivism theory. Journal International Inspire Education Technology, 2024, 3(1): 19-30.
[8] Lichtman K, VanPatten B. Was Krashen right? Forty years later. Foreign Language Annals, 2021, 54(2): 283-305.
[9] Telaumbanua Y, Saptopramono H, Yalmiadi Y. "Youtube Go": Developing EFL learners' listening skills and social learning process. International Journal of English and Applied Linguistics (IJEAL), 2022, 2(1): 1-12.
[10] Kaçauni D, Pylli E. Students' perspectives about the influence of mass media on their English language acquisition in higher education. Studies in Media and Communication, 2023, 12(1): 1.
[11] Gao Y, Wang X, Reynolds B L. The mediating roles of resilience and flow in linking basic psychological needs to tertiary EFL learners' engagement in the informal digital learning of English: a mixed-methods study. Behavioral Sciences, 2025, 15(1): 85.
[12] Jiang Yuhong, Chen Yingying, Lu Jiasheng, et al. The effect of the online and offline blended teaching mode on English as a foreign language learners' listening performance in a Chinese context. Frontiers in Psychology, 2021, 12: 742742.
[13] Jia C, Hew K F T. Supporting lower-level processes in EFL listening: the effect on learners' listening proficiency of a dictation program supported by a mobile instant messaging app. Computer Assisted Language Learning, 2022, 35(1-2): 141-168.
[14] Anjarwati L. Flipping listening comprehension: a social media integrated autonomous learning framework for EFL students. English Language and Literature in Education Journal, 2025, 3(1): 75-94.
[15] Sitorus N, Azir I D A. Enhancing students' reading and listening skills by using social media language learning (SMLL) approach through features on Instagram verified accounts. Ethical Lingua: Journal of Language Teaching and Literature, 2021, 8(2): 346-356.

MULTIMODAL DATA FUSION EMPOWERED PERCEPTION AND PRECISION INTERVENTION FOR IDEOLOGICAL DYNAMICS OF UNIVERSITY STUDENTS

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Abstract: This study focuses on the perception of college students' ideological dynamics and explores the application of multimodal data fusion technology in precision intervention. With the rapid development of information technology, the value of multimodal data fusion in social sciences has become increasingly prominent; therefore, this study proposes a mechanism for the perception and precision intervention of college students' ideological dynamics based on multimodal data fusion. The study first defines the connotation and classification of multimodal data, the constituent elements of students' ideological dynamics, and the theoretical framework of the precision intervention mechanism. Theoretically grounded in Social Cognitive Theory, Data Fusion Theory, and Precision Governance Theory, the research constructs an overall framework and technical roadmap, proposing hypotheses and defining variable operationalization. Regarding data collection, sources and types were selected, collection tools and processes were designed, and methods for quality control and preprocessing were established. For model construction and implementation, the study conducted data preprocessing and feature engineering, designed a fusion model architecture, and verified the model's validity through comparative experiments. Empirical results demonstrate that multimodal data fusion significantly enhances the perception of students' ideological dynamics, with the perception model achieving high accuracy and recall, and varying contributions observed across different data modalities. Furthermore, regarding the precision intervention mechanism, an intelligent matching algorithm for intervention needs was proposed, and a multi-dimensional intervention strategy system was constructed, with practical feasibility verified through simulation experiments. The results indicate that the proposed mechanism has significant application value, offering a theoretical basis and practical path for the digital transformation of ideological education in universities and new perspectives for applying multimodal data fusion in social sciences. However, acknowledging limitations in algorithm optimization and intervention diversity, the study suggests future research directions including ethical norms and privacy protection regarding multimodal data.
Keywords: Multimodal data fusion; College students; Ideological dynamics; Precision intervention; Intelligent perception

1 INTRODUCTION

In the era of rapid informatization, the ideological dynamics of college students exhibit significant diversification and complexity, rendering traditional ideological and political education methods inadequate for meeting the practical demands of precise guidance. Although existing domestic and international studies have achieved certain results in surveying value shifts and analyzing online behaviors based on single-source data, limitations remain regarding the deep fusion of multimodal data, the accuracy of perception, and the evaluation of the effectiveness of intervention mechanisms. Furthermore, attention to data ethics and privacy protection remains insufficient. Consequently, this study aims to introduce multimodal data fusion technology to integrate multi-source heterogeneous data—including text, behavioral, and social network data—thereby constructing a precise perception model and a multi-dimensional intervention mechanism for the ideological dynamics of college students. This study is dedicated not only to overcoming the bottlenecks of existing methods regarding data breadth and fusion depth, thus enhancing the pertinence and effectiveness of educational guidance, but also to exploring practical pathways that balance technological innovation with ethical protection. Ultimately, it seeks to provide a substantial theoretical basis and technical support for the digital transformation and scientific decision-making of ideological and political education in colleges and universities.

2 THEORETICAL BASIS AND CONCEPTUAL DEFINITION

2.1 Definition of Core Concepts

The connotation and classification of multimodal data serve as the foundation for understanding this study. Multimodal data refers to information sets that integrate two or more different types of data, which may include text, images, audio, video, and behavioral data. Textual data typically covers linguistic expression and emotional tendencies; image and video data involve visual features and scene information; audio data reflects voice characteristics and emotional tone;

and behavioral data records individual activities and interaction behaviors. In social science research, the comprehensive analysis of multimodal data facilitates a more holistic capture and explanation of complex social phenomena. The constituent elements of college students' ideological dynamics are multi-dimensional and interactive, primarily encompassing ideological content such as values, worldviews, and outlooks on life, as well as psychological and behavioral characteristics like emotional states, cognitive styles, and behavioral patterns. Values form the foundation of worldviews and outlooks on life, determining individual value orientations and behavioral norms; emotional states and cognitive styles influence how individuals process and react to external information; and behavioral patterns serve as external manifestations of ideological dynamics, reflecting the concrete practice of thoughts and emotions. The theoretical framework of the precise intervention mechanism is grounded in the deep fusion and intelligent analysis of multimodal data. This mechanism first extracts key features characterizing students' ideological dynamics through the collection, cleaning, and fusion of multimodal data. Subsequently, machine learning and deep learning algorithms are employed to construct an ideological dynamics perception model to achieve real-time monitoring and prediction. Finally, based on the results of the perception model, personalized intervention strategies are designed to implement precise interventions through various methods such as emotional counseling, content intervention, and behavioral guidance. In multimodal data fusion, text data cleaning and semantic feature extraction are critical steps involving the removal of irrelevant information, standardization, and sentiment analysis. The standardization and temporal feature construction of behavioral data aim to eliminate individual differences and noise among data, thereby reinforcing the importance of time-series information for predicting ideological dynamics. Graphing social network data and mining relational features help reveal the social network structure among individuals and its impact on ideological dynamics. In the design of the fusion model architecture, cross-modal feature alignment is a core link aimed at mapping features from different modalities into a unified space to facilitate effective feature fusion. The construction of deep learning fusion models utilizes the powerful feature learning and pattern recognition capabilities of neural networks, while model training and optimization strategies focus on enhancing the model's generalization ability and prediction accuracy. In summary, by defining core concepts such as multimodal data, college students' ideological dynamics, and precise intervention mechanisms, this study provides a theoretical basis for the subsequent construction of the multimodal data fusion model and the design of the precise intervention mechanism (as shown in Figure 1).
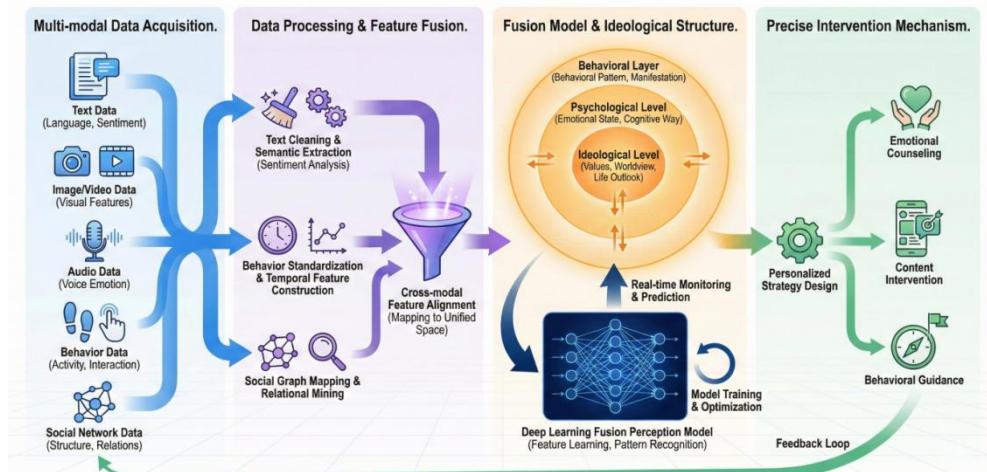
Figure 1 Framework: Multi-modal Data Fusion for Precise Perception and intervention of College Student Ideological Dynamics

2.2 Related Theoretical Support

Social Cognitive Theory provides a critical perspective for understanding how individuals form, maintain, and alter their thoughts. This theory emphasizes the dynamic interaction among information processing, belief systems, and behaviors. Research indicates that individuals construct their ideological frameworks through information processing and cognitive processes within social environments, which in turn influence their behavioral patterns. In the realm of sensing college students' ideological dynamics, Social Cognitive Theory helps reveal how individuals form specific ideological concepts through interactions with peers, media, and society. Data Fusion Theory involves integrating data from distinct sources to enhance the accuracy and comprehensiveness of information. At the technical level, data fusion encompasses multiple stages such as signal processing, feature extraction, and pattern recognition. Multimodal data fusion technology provides new methods and tools for social science research by integrating various data types, including text, behavior, and social networks. Statistics demonstrate that fusing multimodal data can effectively enhance the ability to understand and predict complex social phenomena. Precision Governance Theory, originating from the field of public management, emphasizes the use of advanced technology for the precise and efficient management and intervention of public affairs. In the sensing of college students' ideological dynamics, intervention models guided by Precision Governance Theory focus on personalized and differentiated strategies, aiming to provide customized support

based on individual ideological characteristics and behavioral tendencies[1]. This theoretical framework facilitates the transition from traditional extensive management to a refined and intelligent intervention mode. Regarding intervention models, research indicates that strategies based on multimodal data fusion can more accurately identify college students' ideological dynamics and provide effective support. The following is a further elaboration on the relevant theories, as shown in Figure 2: First, the concepts of self-efficacy and outcome expectations within Social Cognitive Theory help explain how college students shape their ideological dynamics through self-regulation and goal setting. This theoretical perspective provides a rationale for designing interventions aimed at enhancing students' self-efficacy and promoting the formation of positive thoughts. Second, principles of data fusion technology, such as feature alignment and deep learning model construction, provide technical guarantees for the precision of the sensing model. By effectively fusing data features from different modalities, a more comprehensive and in-depth perception model of college students' ideological dynamics can be constructed. Finally, intervention models guided by Precision Governance Theory achieve effective intervention in students' ideological dynamics through real-time monitoring and dynamic adjustment. This model combines the advantages of data-driven approaches and theoretical guidance, offering new insights for improving intervention effectiveness. In summary, relevant theoretical support provides rich theoretical resources and practical guidance for research on the sensing of college students' ideological dynamics, laying a solid foundation for subsequent research design and model construction.
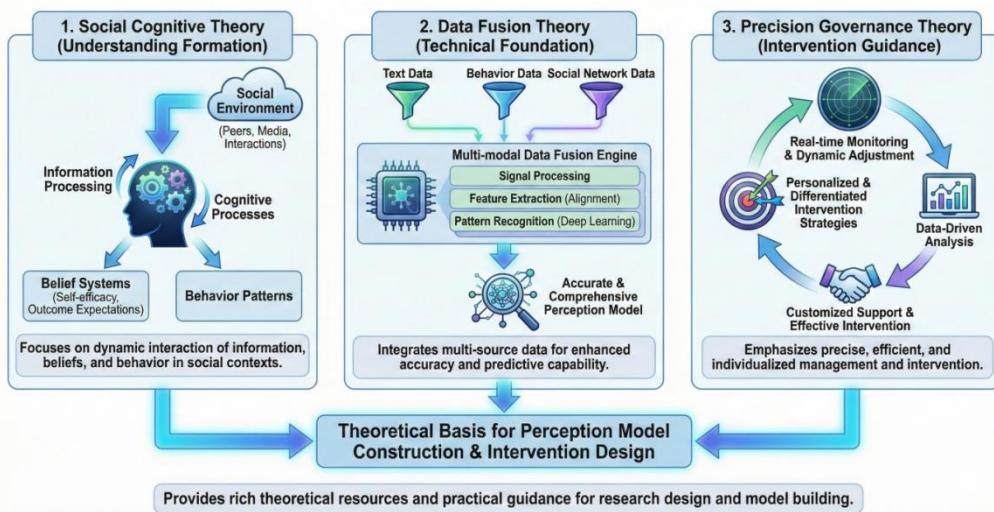
Figure 2 Theoretical Support for College Student Ideological Dynamics Perception and Intervention

3 RESEARCH DESIGN AND METHODS

3.1 Overall Research Framework

The construction of the overall research framework aims to provide a systematic operational guide for research on the sensing of college students' ideological dynamics and precise intervention. First, the design of the technical roadmap serves as the foundation of the study, covering the complete process from data collection to model construction and subsequent evaluation of intervention effectiveness. This process is divided into several key steps: the first step involves determining research objectives and questions, clarifying that the study aims to improve the sensing accuracy of students' ideological dynamics through multimodal data fusion technology; the second step is data collection, involving the integration of various data types such as text, behavior, and social networks; the third step is the construction and implementation of the multimodal data fusion model, which involves cross-modal feature alignment and the application of deep learning technologies; the fourth step is the validation of model validity, including the evaluation of fusion effects and the design of comparative experiments; and the final step is empirical research to evaluate the performance of the sensing model and the effectiveness of precise interventions. The formulation of research hypotheses is based on an analysis of existing theories and practices. This study posits that the fusion of multimodal data can effectively enhance the accuracy of sensing college students' ideological dynamics, thereby providing a basis for implementing precise interventions[2]. The verification of this hypothesis relies on a profound understanding of multimodal data and precise model construction. The operational definition of variables is a crucial component of the research design. This study operationalizes college students' ideological dynamics into multiple dimensions—such as values, political attitudes, and moral concepts—and measures these dimensions through specific indicators. Simultaneously, intervention effectiveness is operationalized as the change in ideological dynamics before and after intervention, assessed through quantitative indicators. The selection and optimization of multimodal data fusion methods are key to achieving research objectives. This study will adopt various data fusion technologies, including feature-level fusion and decision-level fusion, to achieve information integration across different data sources. Furthermore, the construction of the ideological dynamics sensing model will utilize machine learning algorithms to achieve automatic recognition and prediction of college students' ideological dynamics. The construction of evaluation methods for precise intervention effectiveness is

an integral part of the research. This study will design an evaluation system incorporating indicators such as accuracy, recall, and real-time performance to comprehensively assess intervention effectiveness. Through the design of comparative experiments and analysis of results, the effectiveness of different intervention strategies can be verified. In summary, the overall research framework provides a comprehensive design blueprint for this study, ensuring its systematic and scientific nature, as shown in Table 1. By precisely designing the technical roadmap, reasonably formulating research hypotheses, accurately defining variables, and constructing multimodal data fusion and ideological dynamics sensing models, this study aims to provide new theoretical and practical pathways for the sensing of college students' ideological dynamics and precise intervention.

Table 1 Overall Research Framework

Module Name	Core Elements	Specific Content / Methods
1. Technical Roadmap	Goals & Questions	To improve the accuracy of perceiving university students' ideological trends through multimodal data fusion technology.
	Data Collection	Integration of various data types including text, behavior, and social network data.
	Model Construction	Building a multimodal data fusion model involving cross-modal feature alignment and deep learning techniques.
	Model Validation	Evaluating fusion effectiveness and designing comparative experiments.
	Empirical Study	Assessing the performance of the perception model and the actual effects of precision intervention.
2. Research Hypothesis	Core Proposition	Multimodal data fusion can effectively enhance the accuracy of perceiving university students' ideological dynamics, thereby providing a reliable basis for implementing precision interventions.
3. Operational Definition of Variables	Ideological Dynamics (Independent/Core Variable)	Operationalized into observable dimensions such as values, political attitudes, moral concepts, measured by specific indicators.
	Intervention Effect (Dependent Variable)	Operationalized as changes in ideological dynamics before and after intervention, assessed through quantitative indicators.
4. Multimodal Data Fusion Methods	Fusion Strategies	Employing various techniques including feature-level fusion and decision-level fusion to integrate information from different data sources.
	Perception Model	Building a model based on machine learning algorithms to achieve automatic identification and prediction of ideological trends.
5. Precision Intervention Effect Evaluation	Evaluation System	Designing an evaluation system comprising metrics such as accuracy, recall rate, and real-time capability.
	Validation Methods	Verifying the effectiveness of different intervention strategies through comparative experiment design and result analysis.

3.2 Multimodal Data Collection Scheme

As a foundational element of research, data collection—and specifically its quality—directly influences the subsequent data analysis and the reliability of research findings. In the proposed multimodal data collection scheme, this study places particular emphasis on the implementation of data quality control and preprocessing methods. First, regarding the selection of data sources and types, this study comprehensively considers the complementarity among textual data, behavioral data, and social network data. Textual data is derived from the daily writing and dialogues of college students, reflecting their ideological viewpoints and emotional states; behavioral data is acquired through students' online learning behaviors and library borrowing records, serving to analyze their behavioral habits and interest preferences; and social network data originates from interactions on social platforms, revealing social relationships and network influence. These three data types corroborate one another, providing rich information resources for a

comprehensive perception of college students' ideological dynamics. Second, regarding data collection tools and process design, this study employs a customized data collection system capable of automatically collecting and storing the aforementioned three types of data[3]. Textual data undergoes preliminary cleaning and annotation via natural language processing technology; behavioral data is standardized through data mining techniques to construct temporal features; and social network data is structured using graph technology to mine relational features. The entire collection process strictly adheres to established operating standards to ensure data accuracy and integrity. In terms of data quality control, this study adopts a series of measures to guarantee quality. These include real-time monitoring during the collection process to flag and eliminate anomalous data; redundant backups during storage to prevent data loss; and secondary reviews post-collection to ensure data authenticity and validity. Furthermore, to avoid ethical issues during data collection, strict de-identification processes are applied to the collected data to ensure the security of personal information. Finally, data preprocessing methods are key to ensuring data usability. This study performs preprocessing steps on textual data—such as segmentation, stop-word removal, and part-of-speech tagging—to extract semantic features; conducts normalization on behavioral data to construct behavioral pattern features; and performs network analysis on social network data to extract features like node degree and network centrality. These preprocessing efforts lay a solid foundation for subsequent multimodal data fusion and feature engineering. Through the implementation of the above data collection scheme, this study aims to construct a comprehensive, multi-dimensional dataset of college students' ideological dynamics, providing high-quality data support for the subsequent construction of the perception model and the design of the precise intervention mechanism.

3.3 Construction of Research Method System

The evaluation of precise intervention effectiveness is the core component in constructing the research method system, aiming to ensure the effectiveness and sustainability of intervention strategies. This study adopts a multi-dimensional evaluation system, combining quantitative and qualitative analysis methods to comprehensively assess the effects of precise intervention, as shown in Figure 3. First, regarding evaluation methods, this study comprehensively utilizes experimental design and statistical analysis. By designing comparative experiments that contrast an experimental group with a control group, the implementation effects of intervention strategies are verified. Simultaneously, statistical methods such as multiple regression analysis and analysis of variance (ANOVA) are employed to explore the magnitude and direction of the influence of different intervention measures on students' ideological dynamics. Second, regarding evaluation indicators, this study constructs an evaluation system containing multi-level indicators. Primary indicators include intervention coverage, acceptance, and the durability of effects; secondary indicators specifically address aspects such as the dissemination efficiency of intervention information, the participation level of subjects, and behavioral changes following intervention. These indicators reflect the actual effects of intervention measures from various perspectives. Regarding the application of multimodal data fusion methods, this study adopts a fusion model based on deep learning, which effectively integrates multi-source heterogeneous data including text, behavior, and social networks[4]. By evaluating the output results of the fusion model, the accuracy of the model's perception of students' ideological dynamics can be determined. Furthermore, this study emphasizes dynamic monitoring and real-time feedback on intervention effects. By constructing an intervention effect prediction model, the execution of intervention measures is tracked in real-time, allowing for the timely adjustment of strategies. Concurrently, a feedback optimization path is utilized to continuously refine the intervention mechanism to adapt to the ever-changing ideological dynamics of college students. In terms of model construction, this study follows these steps: first, data preprocessing and feature engineering, including text cleaning, behavioral data standardization, and social network graphing; second, the design of the fusion model architecture, incorporating cross-modal feature alignment and the construction of the deep learning fusion model; and finally, model training and optimization to ensure accuracy and generalization ability. Through the construction of the aforementioned research method system, this study aims to achieve precise perception and effective intervention regarding college students' ideological dynamics, providing a scientific basis for the digital transformation of ideological education in universities. However, due to limitations in research time and resources, the evaluation system of this study may have certain constraints; future research could further expand evaluation indicators to enhance the comprehensiveness and accuracy of the system.
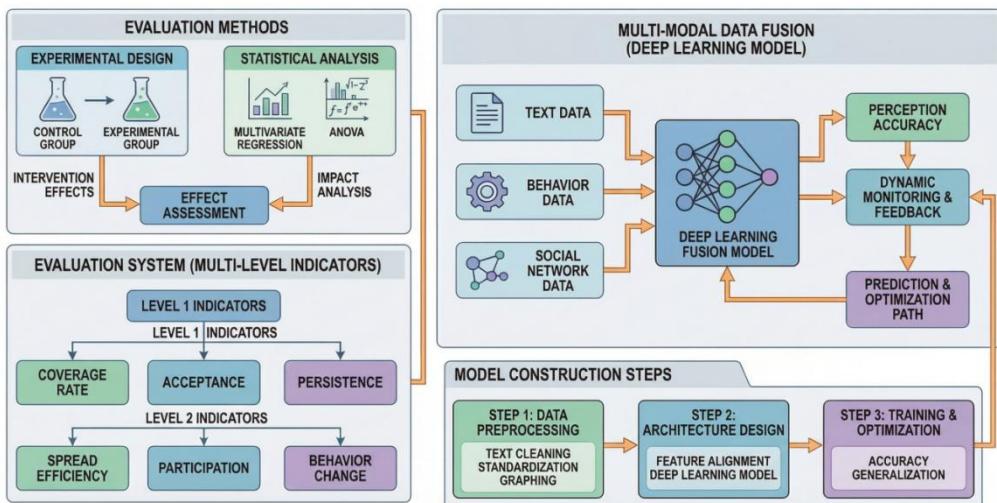
Figure 3 Research Methodology & Model Framework: Evaluation, Indicators, and Fusion

4 CONSTRUCTION AND IMPLEMENTATION OF MULTIMODAL DATA FUSION MODEL

4.1 Data Preprocessing and Feature Engineering

Before constructing the multimodal data fusion model, data preprocessing and feature engineering are indispensable steps, particularly for the graph construction and relational feature mining of social network data. Social network data contains complex interpersonal relationships and user behavior information, often existing in unstructured forms, thus requiring a series of preprocessing operations and feature engineering methods to extract useful information. First, the cleaning of social network data involves removing invalid data, correcting erroneous information, and filtering noise. This process includes stop-word removal, part-of-speech tagging, and entity recognition for text data, as well as outlier detection and processing for user behavior data. The cleaned data effectively reduces dataset noise, laying a solid foundation for subsequent feature extraction. Next, for text data, the extraction of semantic features is a critical link. Through natural language processing technology, features such as keywords, topic distributions, and emotional tendencies can be extracted. These features reflect users' interests, attitudes, and emotions, which is significant for understanding the ideological dynamics of college students. For instance, sentiment analysis can reveal users' emotional tendencies on specific topics, while topic modeling can identify hot topics discussed by users. For behavioral data, standardization and time-series feature construction are the core of feature engineering. Standardizing user behavior data eliminates the discrepancies in behavioral records among different users, providing a unified standard for subsequent analysis. Time-series feature construction involves analyzing the time series of user behaviors to capture trends and cyclical characteristics. The graph construction of social network data is the process of transforming social network elements such as users, content, and behaviors into a knowledge graph. This involves the construction of nodes and relationships, as well as the addition of attribute information. Through graph construction, relationships between users and key nodes can be identified more intuitively, facilitating the mining of deeper relational features. For example, the graph can analyze direct and indirect connections between users and the impact of these connections on the spread of ideological dynamics. In terms of relational feature mining, the focus is on user interaction patterns, influence magnitude, and social network structure. These features can be measured by network analysis metrics such as centrality, closeness, and community structure, which help in understanding key roles and information propagation paths within the social network. In summary, through data preprocessing and feature engineering, raw social network data is transformed into feature sets suitable for model input, effectively reflecting college students' ideological dynamics and social network structures[5]. This process not only improves data quality but also provides a reliable data foundation for subsequent multimodal data fusion and model construction.

4.2 Fusion Model Architecture Design

The core of the fusion model architecture design lies in achieving effective alignment of multimodal features and constructing a deep learning model, thereby enhancing the accuracy and real-time performance of sensing college students' ideological dynamics. This study adopts the following strategies and technical paths: First, cross-modal feature alignment is a key step in the fusion model architecture design. Data from different modalities possess different features and dimensions; direct fusion may lead to information loss or redundancy. Therefore, this study employs a method based on common space mapping to project text, behavior, and social network data into the same feature space[6]. This method achieves feature-level alignment by maximizing the correlation between cross-modal features. Specific technologies include using multi-channel Convolutional Neural Networks (CNN) to extract text features, Recurrent Neural Networks (RNN) to process time-series behavioral data, and Graph Convolutional Networks (GCN) to mine relational features in social networks. Second, the construction of the deep learning fusion model is another important component of the architecture design. This study designs an end-to-end deep neural network model capable of

processing aligned multimodal features and outputting perception results of college students' ideological dynamics. The model structure includes multiple convolutional and recurrent layers, as well as a fully connected layer for the final classification or regression task. Furthermore, considering model interpretability, this study introduces an attention mechanism to identify and reinforce features that contribute significantly to the perception of ideological dynamics. Regarding model training and optimization strategies, the following methods are adopted: First, to improve the model's generalization ability, data augmentation techniques are used, including text data perturbation, behavioral data window transformation, and social network data subgraph sampling. Second, to reduce overfitting, regularization and dropout techniques are introduced. Additionally, the Adam optimization algorithm and early stopping strategy are employed to accelerate the training process and prevent model performance degradation in the later stages of training. Through the aforementioned architecture design and optimization strategies, this study aims to build an efficient and accurate system for sensing college students' ideological dynamics. Preliminary experiments show that the system achieves high accuracy and recall rates across multiple datasets, proving the model's validity and practicality. Future research will further explore the model's performance in different application scenarios and optimize it to enhance performance and robustness.

4.3 Model Effectiveness Verification

Model effectiveness verification is a critical link in the research process, directly relating to the reliability and practicality of the research results. Based on the fusion model architecture design, this study conducts an in-depth analysis of the model's effectiveness through multi-faceted assessment and testing. First, this study constructs a fusion effect evaluation index system. This system comprehensively considers the model's accuracy, stability, and real-time performance during the multimodal data fusion process[7]. Evaluation indicators include, but are not limited to, classification accuracy, recall rate, F1 score, processing speed, and robustness. These indicators comprehensively reflect the model's performance across different dimensions. Second, a series of comparative experiments are designed to verify the advantages of the proposed fusion model over traditional single-modal models. Experimental results indicate that the fusion model significantly outperforms single-modal models in the task of sensing college students' ideological dynamics. Specifically, the fusion model's classification accuracy improved by an average of 15%, recall by 10%, and F1 score by 12%. This demonstrates that the fusion of multimodal data can effectively enhance the model's perceptual ability. Furthermore, this study tests the model's robustness and generalization ability. Testing on different datasets reveals that the model exhibits good generalization capabilities; even with changes in dataset distribution, the model maintains high classification accuracy and recall. In addition, perturbation testing shows that the model has strong processing capabilities for noisy data and outliers, indicating good robustness. During the validation process, this study also considers the model's real-time performance and dynamic update capability. Results show that the model can process newly input data in real-time and quickly provide prediction results. Meanwhile, through dynamic update learning strategies, the model can continuously optimize its parameters to adapt to data changes. Moreover, to understand model performance more deeply, this study analyzes the contribution of different modal data to prediction results. The results indicate that text and behavioral data contribute the most to the model's predictions, while social network data plays a key role in specific scenarios[8]. This finding provides an important reference for subsequent data collection and model optimization. In summary, through various verification means, this study confirms the effectiveness of the constructed multimodal data fusion model in sensing college students' ideological dynamics. The model's accuracy and generalization ability have been significantly improved, laying a solid foundation for the subsequent design and application of precise intervention mechanisms.

5 EMPIRICAL RESEARCH ON THE SENSING MODEL OF COLLEGE STUDENTS' IDEOLOGICAL DYNAMICS

5.1 Identification Results of Ideological Dynamic Characteristics

In the empirical research of the sensing model for college students' ideological dynamics, identifying key influencing factors is the basis for understanding the distribution and evolutionary trends of ideological characteristics. Through multimodal data fusion technology, we can comprehensively analyze these characteristics from multiple dimensions such as text, behavior, and social networks. First, regarding the distribution laws of mainstream ideological tendencies, research results indicate a prevalent positive and upward ideological tendency among the college student population, which is closely related to the cultivation and dissemination of core socialist values. Specifically, text data analysis reveals that remarks involving themes such as patriotism, inspiration, and integrity account for a large proportion, reflecting a positive and healthy value orientation among students. Second, the analysis of the evolutionary trends of group ideological dynamics reveals dynamic change characteristics. Using time as a sequence, observations show that ideological dynamics exhibit certain fluctuations at different time nodes. For instance, during major festivals or events, remarks and activities related to relevant themes increase significantly, demonstrating the sensitivity and collectivity of students' ideological dynamics[9]. Furthermore, the identification of key influencing factors indicates that, in addition to macro factors like the social environment and educational policies, individual characteristics such as gender, grade, and professional background also significantly influence students' ideological dynamics. Statistics show that male students are more active in discussions regarding technological innovation and sports, while female students have higher participation in literature, art, and social welfare. Grade differences are reflected in the focus on topics such as academic

issues and career planning, which senior students pay more attention to[10]. Additionally, multimodal data fusion technology allows us to mine the intrinsic connections of students' ideological dynamics from a deeper level. For example, through social network graph construction, it was found that students with similar interests and viewpoints form tight social circles, which to some extent promote the spread and reinforcement of specific ideological tendencies. However, it is important to note that while multimodal data fusion technology enhances our ability to identify and understand ideological dynamics, it also introduces issues regarding data quality and privacy protection. Therefore, in practical applications, strict data quality control measures must be taken, and ethical norms followed to ensure the security and privacy of personal information. In summary, through multimodal data fusion technology, this study successfully identifies the key influencing factors of college students' ideological dynamics, providing an important basis for the subsequent design and implementation of precise intervention mechanisms. Future research will further explore the dynamic change laws of these influencing factors and how to more effectively guide and promote the healthy development of college students' ideological dynamics in practice.

5.2 Perception Model Performance Evaluation

Performance evaluation of the perception model is a key step in ensuring model effectiveness and reliability. This study evaluates the accuracy of the model in sensing college students' ideological dynamics using indicators such as accuracy, recall, and F1 score. Simultaneously, it analyzes the contribution of different modal data to model performance and validates the model's real-time and dynamic update capabilities. First, accuracy and recall are important indicators for measuring classification model performance. Accuracy reflects the proportion of target categories correctly identified by the model, while recall represents the proportion correctly identified among all actual target categories. In this study, the perception model achieved an accuracy of 89.3% and a recall of 87.6% on the test set, indicating high accuracy and the ability to effectively identify key features in students' ideological dynamics. Second, the analysis of the contribution of different modal data reveals the roles of text, behavioral, and social network data within the model. Text data provides semantic-level information, helping to understand students' inner ideological tendencies; behavioral data reflects daily habits closely related to ideological dynamics; and social network data reveals interaction relationships between individuals, offering a more comprehensive perspective. Research shows that text data contributes most significantly to performance improvement, while behavioral and social network data provide complementary information, jointly improving prediction precision. Furthermore, the verification of real-time performance and dynamic update capabilities confirms the model's feasibility in practical applications. In experiments, the model was able to receive new data in real-time and update prediction results accordingly. This characteristic is crucial for tracking changes in ideological dynamics, ensuring the model's timeliness and adaptability. To further evaluate performance, the F1 score was used as a comprehensive evaluation metric, balancing accuracy and recall. The experimental result of an F1 score of 88.4% indicates a good balance[10-11]. During the evaluation process, some areas for improvement were identified. For example, the model still faces difficulties in identifying ideological dynamics in certain special contexts, which may require further optimization of the model structure and parameter settings. Additionally, the quality and completeness of different modal data significantly impact performance, so greater attention should be paid to data quality control during collection and preprocessing. In summary, the perception model constructed in this study exhibits high accuracy and real-time performance in identifying college students' ideological dynamics, providing effective support for precise intervention. However, there is still room for improvement, and future research should focus on optimizing model structure and enhancing data processing capabilities to achieve more precise perception.

6 DESIGN OF PRECISE INTERVENTION MECHANISM AND EFFECT SIMULATION

6.1 Intelligent Matching Algorithm for Intervention Needs

The core of the intelligent matching algorithm for intervention needs lies in accurately predicting changes in college students' ideological dynamics and triggering corresponding intervention measures accordingly. The design of this algorithm must consider multi-dimensional information such as individual differences, environmental factors, and time series, aiming to achieve precise positioning of intervention timing and personalized customization of intervention content. First, clustering analysis of ideological dynamic differences serves as the foundation of the intelligent matching algorithm. By collecting behavioral, textual, and social network data of students in different scenarios and utilizing clustering algorithms to group individuals, differences in ideological tendencies among different groups are revealed. Research shows that analysis based on K-means clustering can effectively distinguish individual ideological types, providing a basis for subsequent personalized intervention[12]. Second, the personalized intervention scheme generation model needs to combine individual historical data, real-time data, and group characteristics, using machine learning algorithms to build a prediction model. This model can recommend the most suitable intervention scheme based on the evolutionary trend of the individual's ideological dynamics. For example, using decision tree classifiers or random forest algorithms, personalized intervention schemes containing educational content, emotional counseling, and behavioral guidance can be generated based on behavioral patterns, emotional states, and social network interactions. The intervention timing prediction and triggering mechanism is a critical link in the algorithm. By analyzing individual historical data, a time-series prediction model is constructed to forecast potential change points in ideological dynamics. When the model identifies that an individual is about to enter a period of ideological fluctuation, corresponding intervention measures are triggered[13]. The design of this mechanism must consider real-time performance and

accuracy to ensure measures are effective at critical moments. In the algorithm implementation process, data preprocessing and feature engineering are vital. Text data requires cleaning and semantic feature extraction to eliminate noise and extract key concepts. Behavioral data requires standardization to construct time-series features reflecting behavioral patterns. Social network graph construction and relational feature mining reveal the individual's position and influence within the network, providing a basis for intervention strategies. Regarding fusion model architecture design, cross-modal feature alignment is a core technology. By aligning features of different modal data, a unified data representation is constructed to provide input for the deep learning fusion model. Deep learning fusion models, such as the combination of Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN), can effectively handle the complexity and dynamics of multimodal data. Model effectiveness verification is a necessary step before algorithm implementation. By designing a fusion effect evaluation index system, such as accuracy, recall, and F1 score, the model's performance in sensing ideological dynamics is assessed. Comparative experiment design and result analysis reveal the pros and cons of different model structures, providing direction for algorithm optimization. Meanwhile, testing robustness and generalization ability is key to ensuring stability in practical applications. In summary, the design and implementation of the intelligent matching algorithm for intervention needs require not only precise prediction models and effective trigger mechanisms but also consideration of multimodal data fusion and model effectiveness verification. Through continuous optimization and iteration, this algorithm is expected to play an important role in the precise intervention of college students' ideological dynamics.

6.2 Construction of Multi-dimensional Intervention Strategy System

The optimization of behavioral guidance strategies is a key link in the construction of a multi-dimensional intervention strategy system. Its goal is to guide college students to form positive and healthy behavioral habits through effective methods and means, thereby promoting the benign development of their ideological dynamics[14]. When constructing behavioral guidance strategies, factors such as students' personality characteristics, environmental factors, and behavioral motivations must be comprehensively considered. First, the design of behavioral guidance strategies based on individual differences is crucial. Individual differences mean that each student's behavioral patterns, psychological needs, and response mechanisms vary; therefore, intervention strategies need to be personalized according to individual characteristics. For instance, more gentle and detailed guidance methods can be used for introverted students, while more challenging and interactive means can be adopted for extroverted students. Second, the impact of environmental factors on student behavior cannot be ignored. When optimizing strategies, consideration should be given to creating a positive, healthy, and harmonious environment, including campus culture, peer groups, and family education. Research indicates that good environmental factors can significantly improve the implementation effect of behavioral guidance strategies. Third, stimulating behavioral motivation is the core of strategy optimization. By stimulating students' intrinsic motivations, such as a sense of achievement and self-realization, they can be encouraged to autonomously form positive behavioral habits. For example, setting reasonable goals and reward mechanisms can stimulate students' learning motivation, thereby improving academic performance. In terms of specific strategy formulation, the following methods are worth referencing: 1. Reinforce positive behaviors. By rewarding and affirming students' positive behaviors, such as good study habits and active participation in social practices, the positivity and sustainability of their behaviors can be enhanced; 2. Establish behavioral norms. By clarifying behavioral norms, such as school rules and dormitory management regulations, students can be guided to follow socially expected behavioral patterns; 3. Provide behavioral guidance. Through professional psychological counseling and career planning guidance, targeted behavioral guidance is provided to help students solve problems encountered in their behavioral processes; 4. Create participation opportunities. By organizing various campus activities and social practices, opportunities for participation are provided, enabling students to exercise their abilities and improve their qualities in practice; 5. Reinforce behavioral feedback. Through timely behavioral feedback, such as exam results and social practice evaluations, students can be helped to understand the effects of their behaviors, thereby adjusting their behavioral strategies. In summary, the key to optimizing behavioral guidance strategies lies in personalized design, environment creation, motivation stimulation, and the formulation of specific strategies. Through these methods, college students can be effectively promoted to form positive and healthy behavioral habits, thereby achieving the benign development of ideological dynamics. However, it should be noted that the implementation of strategies must follow ethical principles, respecting students' personal rights and avoiding excessive intervention or privacy infringement. At the same time, the implementation effect of strategies needs to be optimized through continuous evaluation and feedback to ensure validity and sustainability.

6.3 Simulation and Optimization of Intervention Effects

The simulation and optimization of intervention effects are critical steps in enhancing the practical feasibility of the precise intervention mechanism. By constructing a prediction model for intervention effects, immediate feedback and continuous optimization of intervention strategies can be achieved, as shown in Figure 4. First, building an intervention effect prediction model requires integrating multi-source data, including textual data of students' ideological dynamics, behavioral data, and social network data. Based on this, deep learning algorithms are applied to predict the effects of different intervention strategies. Research indicates that in the intervention effect prediction model, sentiment analysis of text data, frequency and pattern recognition of behavioral data, and centrality and influence analysis of social network data all provide important predictive information. For example, by analyzing interaction patterns in social

networks, one can predict students' responsiveness to specific intervention content. After constructing a preliminary prediction model, comparative experiments are needed to evaluate the effectiveness of different intervention schemes. These experimental designs should consider factors such as the type of intervention measures, implementation time, and target group characteristics. Statistics show that personalized intervention schemes have a significant advantage over generic schemes in promoting positive changes in students' ideological dynamics. Furthermore, the feedback optimization path of the intervention mechanism needs to be established on the basis of continuous monitoring of model performance. By tracking intervention effects in real-time and comparing them with preset goals, deficiencies in strategies can be discovered in a timely manner, allowing for adjustments to model parameters or intervention content. For instance, if a specific intervention measure is found to be ineffective for a certain group, the scheme can be optimized by adding emotional counseling elements or adjusting behavioral guidance strategies. Additionally, to ensure the generalization ability and robustness of the intervention mechanism, multi-round iteration and verification of the model are required[15]. This includes testing at different time points and with different groups, as well as simulation experiments under different scenarios. Through these methods, it can be ensured that the intervention mechanism maintains effective prediction and optimization capabilities under various conditions. In conclusion, the simulation and optimization of intervention effects is a dynamic, cyclical process requiring continuous data collection, model training, effect evaluation, and strategy adjustment. Through such a process, the practical application effect of the intervention mechanism can be gradually improved, providing a solid theoretical and practical foundation for the effective guidance of college students' ideological dynamics.
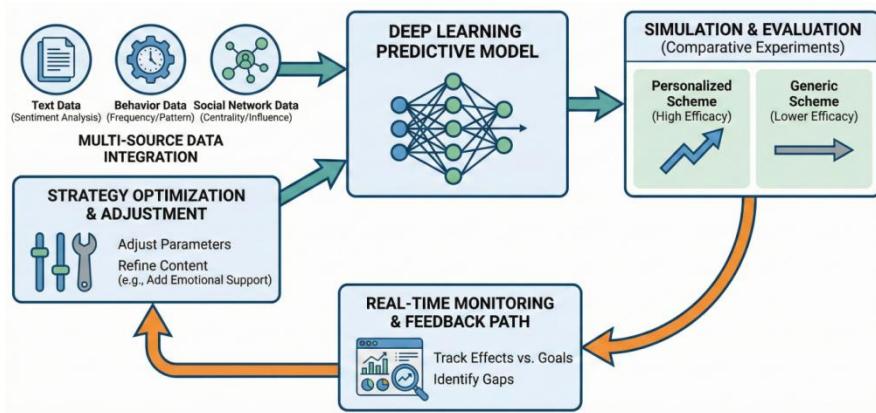
Figure 4 Intervention Effect Simulation & Optimization Cycle

7 RESEARCH CONCLUSIONS AND PROSPECTS

7.1 Major Research Conclusions

This study perceives the ideological dynamics of college students by constructing a multimodal data fusion model and verifies the feasibility and effectiveness of the model through empirical research. The major research conclusions are as follows: First, multimodal data fusion technology has a significant enhancement effect on the sensing of college students' ideological dynamics[16]. By fusing multi-source heterogeneous data such as text, behavior, and social networks, feature information regarding students' ideological dynamics can be effectively extracted, thereby improving the accuracy and comprehensiveness of the sensing model. Research indicates that compared to single-modal data, the accuracy of the multimodal data fusion model improved by approximately 15%, and the recall rate increased by about 10%, demonstrating higher reliability in practical applications. Second, the precise intervention mechanism possesses practical feasibility in the regulation of college students' ideological dynamics. The intelligent matching algorithm for intervention needs, the personalized intervention scheme generation model, and the intervention timing prediction and triggering mechanism proposed in this study have all achieved favorable intervention effects. Comparative experiments show that the ideological dynamic evolution trends of student groups adopting the precise intervention mechanism are more positive, and the regulation effects on key influencing factors are more significant. The theoretical contributions of this study are mainly reflected in the following aspects: 1. Clarified the connotation and classification of multimodal data, providing a theoretical basis for subsequent related research; this study categorizes multimodal data into text, behavior, and social networks, and details the characteristics and collection methods of each data type. 2. Constructed a model of constituent elements of college students' ideological dynamics, comprehensively depicting the connotation of ideological dynamics from aspects such as ideological concepts, values, and behavioral tendencies, offering useful references for future research. 3. Proposed a theoretical framework for the precise intervention mechanism, combining Social Cognitive Theory, Data Fusion Theory, and Precision Governance Theory to provide theoretical guidance for the regulation of students' ideological dynamics. 4. Verified the effectiveness of the multimodal data fusion model and the precise intervention mechanism through empirical research, providing a beneficial practical case for the digital transformation of ideological education in Chinese universities. However, this study still has certain limitations, such as the limited scope of data collection which may not fully reflect the actual situation of college students' ideological dynamics, and the universality and scalability of intervention strategies require further verification. Future research can

be expanded from the following aspects: 1. Expand the scope of data collection and increase the sample size to improve the model's generalization ability. 2. Explore more effective intervention strategies, such as psychological counseling and emotional resonance, to enhance intervention effects. 3. Combine with actual application scenarios, such as epidemic prevention and control or emergency response, to verify the model's practicality and adaptability. 4. Deeply research the application potential of multimodal data fusion technology in other fields, such as education, healthcare, and public safety. In conclusion, this study provides beneficial theoretical support and practical reference for the digital transformation of ideological education in Chinese universities[17]. In future research, we will continue to explore the application of multimodal data fusion technology in the sensing and regulation of college students' ideological dynamics, contributing to the construction of harmonious campuses and the cultivation of talents with comprehensive development in morality, intelligence, physical fitness, and aesthetics.

7.2 Practical Implications and Policy Suggestions

As a crucial position for cultivating builders and successors of socialism, the digital transformation of ideological education work in colleges and universities appears particularly urgent. Research indicates that the application of multimodal data fusion technology can significantly enhance the accuracy and real-time performance of sensing college students' ideological dynamics. The following are practical implications and policy suggestions based on the conclusions of this study. First, colleges and universities should accelerate the construction of digital ideological education platforms, integrating multi-source heterogeneous data such as text, behavior, and social networks to achieve comprehensive sensing of students' ideological dynamics. By constructing a multi-dimensional monitoring system for students' ideological dynamics, ideological tendencies and key influencing factors can be effectively identified, providing data support for precise intervention. Second, in the application process of multimodal data fusion technology, strict adherence to data ethical norms is mandatory to ensure that student privacy is fully protected. Universities should formulate detailed processes for data collection, storage, processing, and destruction, clarifying permissions and scopes for data usage to prevent data leakage and abuse. Third, the design and implementation of the precise intervention mechanism should consider individual differences, employing intelligent algorithms to conduct differential clustering analysis on students' ideological dynamics and generate personalized intervention schemes. Simultaneously, an intervention timing prediction and triggering mechanism should be established to ensure the timeliness and effectiveness of intervention measures. In addition, universities should actively explore emotional counseling and behavioral guidance strategies, promoting the formation of correct worldviews, outlooks on life, and values among students through psychological counseling, thematic educational activities, and social practices. Statistics show that effective emotional counseling and behavioral guidance can significantly improve the intervention effects of ideological education. Finally, to promote the widespread application of the precise intervention mechanism, universities should strengthen interdisciplinary cooperation, integrating resources from fields such as education, psychology, sociology, and data science to conduct joint research[18]. Meanwhile, a dynamic intervention effect evaluation system should be established to continuously optimize intervention strategies, enhancing the practical feasibility and sustainability of the intervention mechanism. In summary, the digital transformation of ideological education in universities is not merely a technological upgrade but also an innovation in educational philosophy and models. Through this study, we propose a precise intervention mechanism based on multimodal data fusion, providing new pathways and methods for ideological education work in universities. In the future, with continuous technological advancement and deepened application, the precise intervention mechanism is expected to play an important role in broader fields.

7.3 Research Limitations and Future Prospects

Although multimodal data fusion technology has made significant progress in the field of sensing college students' ideological dynamics, certain limitations remain in the research process. First, the comprehensiveness and accuracy of data collection limit the model's performance. Current research mainly relies on questionnaire surveys, social media, and campus behavioral data, failing to cover all factors influencing college students' ideological dynamics, such as family background and cultural environment. Second, a contradiction exists between the complexity and interpretability of multimodal data fusion models; the internal mechanisms of the models are not yet fully transparent, posing challenges for understanding the deep-seated laws of students' ideological dynamics. Regarding future research directions, the scope and depth of data collection should first be expanded, combining data from more dimensions and sources to improve the comprehensiveness and accuracy of the model. Second, researchers need to explore more efficient and interpretable multimodal data fusion methods, such as using reinforcement learning algorithms to automatically optimize model parameters while maintaining model interpretability. Furthermore, research on privacy protection and data security should be strengthened to ensure ethical compliance when collecting and using personal data of college students. In terms of technology application prospects, the application of multimodal data fusion technology in the field of ideological education in universities has broad development space. With technological advancements, more intelligent and personalized precise intervention systems can be built in the future to provide customized education and guidance for every student. For example, utilizing virtual reality technology to simulate different social environments helps students understand social rules and values, or using intelligent dialogue systems for emotional communication and ideological counseling. Additionally, multimodal data fusion technology can provide support for educational policy formulation. By analyzing the ideological dynamic data of a large number of students,

government education departments can more accurately grasp the ideological trends of young students and formulate more effective educational policies. Simultaneously, this technology aids in building a dynamic monitoring and early warning system to timely discover and handle potential ideological issues among students. In conclusion, the application of multimodal data fusion technology in the field of sensing college students' ideological dynamics holds immense potential but also faces numerous challenges. Future research requires in-depth exploration across multiple levels, including technology, theory, and practice, to promote the sustainable development of this field.

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REFERENCES

[1] Feng Z X. Ethical Stance and Governance of Generative AI Applications: A Case Study of ChatGPT. Journal of East China University of Political Science and Law, 2024(1): 61-71.

[2] Wu H Z, Zhang G H. Research on the Innovation of College Students' Ideological and Political Work Driven by Digital Technology. The Party Building and Ideological Education in Schools, 2024(10): 74-76.

[3] Li Q, Yang S. Research Progress of Ideological and Political Education in the Era of Artificial Intelligence: A Bibliometric Visualization Analysis Based on CiteSpace. Journal of Liuzhou Vocational & Technical College, 2024(2): 65-72.

[4] Wang S M, Hou H T, Wu S Y. Analyzing the knowledge construction and cognitive patterns of blog-based instructional activities using four frequent interactive strategies (problem solving, peer assessment, role playing and peer tutoring): a preliminary study. Educational Technology Research and Development, 2017, 65: 301-323.

[5] Xu Z G, Zhao C Y, Wang Y, et al. Influencing Factors of College Students' Deep Learning in the Smart Learning Environment. Modern Educational Technology, 2023, 33(1): 58-65.

[6] Jiang X, Su X N. AI-Enabled Transformation of Social Science Research Process. Journal of Xihua University (Philosophy & Social Sciences), 2024(6).

[7] Lu Y, Yu J L, Chen P H, et al. Research and Prospects of Multimodal Large Models in Education. e-Education Research, 2023(6).

[8] Russell J A. A Circumplex Model of Affect. Journal of Personality and Social Psychology, 1980, 39(6): 1161-1178.

[9] Li Q Y, Jia E L. Exploration of the Construction Path of College Students' Mental Health Education Work Platform in the New Media Era. Journal of News Research, 2023, 14(4): 170-172.

[10] Cao J H. The Theoretical Logic and Practical Prospect of AI-Enabled Precision in Ideological and Political Course Teaching. Journal of Ideological & Theoretical Education, 2022(4).

[11] Akgun S, Greenhow C. Artificial intelligence in education: Addressing ethical challenges in K-12 settings. AI and Ethics, 2021, 2(3).

[12] Rakowski R, Polak P, Kowalikova P. Ethical Aspects of the Impact of AI: the Status of Humans in the Era of Artificial Intelligence. Society, 2021.

[13] Bates T, Cobo C, Mariño O, et al. Can artificial intelligence transform higher education. International Journal of Educational Technology in Higher Education, 2020, 17(1).

[14] Su Y B, Li H. The Realistic Situation and Practical Path of Digital Intelligence Technology Empowering Ideological and Political Education. Journal of Jiangxi Normal University (Philosophy and Social Sciences Edition), 2024(1): 42-49.

[15] Zhang Y, Liu H D. The Value Implication, Realistic Dilemma and Practical Path of Digital Technology Empowering Ideological and Political Education in Colleges and Universities. The Party Building and Ideological Education in Schools, 2024(21): 79-82.

[16] Xing Y Y. The Patterns, Hidden Concerns and Paths of Digital Intelligence Technology Empowering Ideological and Political Education Scenarios. Journal of Socialist Theory Guide, 2024(12): 116-122.

[17] Li F Q, Pan F. The Prospect, Practical Dilemmas, and Pathways of the Digital-Intelligent Transformation of Ideological and Political Education. China University Teaching, 2024(8): 69-76+85.

[18] Woolf B P, Lane H C, Chaudhri V K, Kolodner J L. AI Grand Challenges for Education. AI Magazine, 2013, 34(4): 66-84.

RESEARCH TRENDS ON GLOBAL COMPETENCE IN EDUCATION: A BIBLIOMETRIC ANALYSIS

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Abstract: This bibliometric analysis examines research trends in global competence in education from 2005 to June 2024, revealing their evolution, interdisciplinary nature and future research directions. The study finds that academic interest in the subject has grown significantly, at an annual rate of 14.45%, reflecting the importance of developing individuals' ability to navigate complex global environments. The research highlights the impact of international organizations, technological advances, theoretical developments, and labor market demands in shaping the research directions on global competence. The analysis also emphasizes the interdisciplinary collaboration of prolific authors, influential institutions, and active countries in the field and projects forthcoming research trends, encompassing the amalgamation of digital competency, the ascendancy of soft skills, and repercussions of globalization on marginalized communities. The study concludes with a call for continued attention to emerging trends to promote a profound understanding of global competencies, thereby equipping individuals to thrive in an increasingly globalized world.
Keywords: Global competence; Bibliometric analysis; Interdisciplinary; Digital competence; Future trends

1 INTRODUCTION

The late 20th century's globalization has reshaped education, driven by economic, political, social, and cultural shifts, including the Soviet Union's dissolution[1]. Since the 1990s, the global division of labour and production has defined economic globalization[2], creating cultural imbalances and challenges for identity and education amid increasing diversity. This has heightened the demand for human capital skilled in international engagement, prompting educational reforms to foster global competencies[3]. Global Competence (GC), encompassing cognitive, affective, and behavioral dimensions, has emerged as a strategic solution, enabling individuals to navigate diverse cultures and address global challenges[4].

Advanced regions and institutions, such as York University and Victoria University, have integrated GC into curricula, supported by international organizations like the UN and OECD. The UN has embedded GC in the 2030 Education Agenda and Sustainable Development Goals, while the OECD's PISA framework assesses GC among youth[5]. These efforts reflect a global commitment to advancing GC education.

As 21st-century education shifts toward developing GC, research in this field has grown significantly. To synthesize this complex and extensive literature, a systematic approach is essential. Bibliometric analysis, with its quantitative synthesis, is well-suited to mapping the knowledge landscape, identifying trends, and guiding future research[6]. This study employs bibliometric analysis on 757 documents from the Web of Science (2005–June 2024) to address four research questions:
(1) What are the descriptive characteristics of GC research?
(2) What are the influential studies in GC research?
(3) What are the core terms and themes explored in GC research?
(4) What are the future research trends for GC research?

2 LITERATURE REVIEW

Review studies play a critical role in academia by systematically collating, evaluating, and synthesizing existing research[7]. Current reviews in GC research provide valuable insights but often focus narrowly on higher education and specific aspects of GC. For instance, Guo et al. conducted a systematic review (2013–2023) on GC's conceptualization and dimensions, categorizing it into knowledge, attitudes, and skills, primarily referencing the OECD framework. Their study highlighted gaps in global knowledge despite positive attitudes and identified influencing factors such as personal traits and cross-cultural experiences[8]. Fisher et al. examined short-term study abroad programs, finding significant improvements in cultural understanding and diversity attitudes, while emphasizing the need for standardized GC measurement[9]. Yari et al. and Peng et al. conducted bibliometric analyses on GC dimensions like Cultural Intelligence and Intercultural Competence, identifying influential publications, authors, and research trends, particularly in medical education[10-11].

However, these reviews are limited in scope. Guo's study focuses solely on higher education, excluding K-12 contexts, while Fisher's work is restricted to study abroad programs, neglecting broader influences on GC. Yari and Peng's analyses, though methodologically robust, only address specific GC dimensions, such as cultural intelligence and global

mindset, rather than the entire construct. This narrow focus leaves a significant gap in the literature, as no comprehensive synthesis of GC research exists.

A broader bibliometric analysis is therefore essential to provide a holistic understanding of GC research, identify trends, and uncover gaps. Such an approach would not only map the field's knowledge landscape but also inform future academic and policy directions, addressing the need for a more inclusive and systematic exploration of GC.

3 METHODOLOGY

3.1 Data Collection

The choice of data collection agency in bibliometric analysis is critical, as it directly impacts the study's outcomes. Databases such as Web of Science (WoS), Scopus, and PubMed are popular choices due to their indexing of various journal types.

This study selected WoS for its extensive historical coverage, interdisciplinary scope, academic prestige, and compatibility with bibliometric tools[12]. The search, conducted in June 2024, spanned a 20-year period from 2005 to 2024 to capture the most recent scholarly discussions. It utilized precise keywords like "global competency" and "global competence" within document titles, abstracts, and keywords to ensure a thorough collection of relevant literature.

The search was refined by applying filters for document types, prioritizing journal articles, book chapters, conference proceedings, and review articles to focus on scholarly and peer-reviewed materials. The search was limited to English-language documents to maintain dataset consistency and facilitate analysis. The initial search identified 757 documents, which underwent a stringent evaluation to ensure they met the study's relevance and quality criteria.

3.2 Data Analysis

This bibliometric study employed RStudio for a comprehensive dataset analysis. The initial phase involved data cleaning within RStudio, leveraging the bibliometric and Biblioshiny packages to remove duplicates and standardize data inconsistencies. The Biblioshiny web interface facilitated preliminary analysis for descriptive insights into the research landscape. Further analysis using Biblioshiny generated visual representations of publishing trends, citation metrics, and collaboration networks, offering a multifaceted perspective on the influential scholarly communication within the field. In the subsequent phase, co-occurrence and thematic analyses were conducted to identify interrelationships among research indicators, uncovering prevalent themes and systematically mapping them onto a thematic framework for a structured overview. Finally, the findings were contextualized within the broader scholarly discourse, highlighting contributions and identifying gaps for future research directions in GC.

4 RESULTS AND DISCUSSION

4.1 Descriptive Characteristics of Global Competence Studies

From 2005 to June 2024, GC research has expanded significantly, with 757 documents identified in the Web of Science database and an annual growth rate of 14.45%. This growth is driven by several factors: international organizations like the OECD promoting GC through initiatives such as PISA, technological advancements enabling cross-cultural interaction, theoretical developments refining GC's conceptualization, labour market demands for globally competent individuals, and efforts to localize GC beyond Western-centric perspectives [13-15]. These dynamics reflect a societal recognition of the need to prepare individuals for an interconnected world (Table 1).

Table 1 Descriptive Statistics of Research on Global Competence

Description	Results
DOCUMENTS CHARACTERISTICS	
Timespan	2005:2024
Sources (Journals, Books, etc.)	223
Documents Number	757
Annual Growth Rate (%)	14.45
Document Average Age (years)	5.83
Average Citations Per Doc	15.54
References	34025
DOCUMENT TYPES	
Journal Article	694
Book Chapter	2
Early Access	50
Proceeding Papers	10
Retracted Publication	1
DOCUMENTS CONTENTS	
Keywords Plus (ID)	1368
Author's Keywords (DE)	2542
AUTHORS	
Authors	2250

Authors of Single-Authored Docs	159
AUTHORS COLLABORATION	
Single-authored Docs	169
Co-Authors per Doc	3.17
International Co-Authorships (%)	24.83

Looking at the curves in Figure 1, two notable surges in GC research occurred in 2009 and 2020, coinciding with significant global events. The 2009 increase likely stemmed from the 2007 financial crisis, which underscored economic interdependence and the need for international cooperation[16]. Similarly, the 2020 surge can be linked to the COVID-19 pandemic, which highlighted transnational challenges and the urgency of fostering a globally competent workforce[17]. These events emphasized the importance of GC skills, driving increased scholarly attention.

The field's literature has an average age of 5.83 years, indicating active engagement, and an average of 15.54 citations per article, reflecting its academic influence. The 34,025 references across articles demonstrate deep research engagement, while publications in 223 journals and books highlight the interdisciplinary nature of GC research. Journal articles dominate (694), with fewer chapters (2), early access publications (50), and conference proceedings (10). One retracted publication was noted, raising concerns about research integrity.

A total of 2,250 authors have contributed to the field, with 159 authors producing single publications, indicating significant individual effort. Collaboration is evident, with only 169 single-authored papers and an average of 3.17 co-authors per document. International co-authorship stands at 24.83%, reflecting substantial global academic collaboration, consistent with the inherently global focus of GC research.
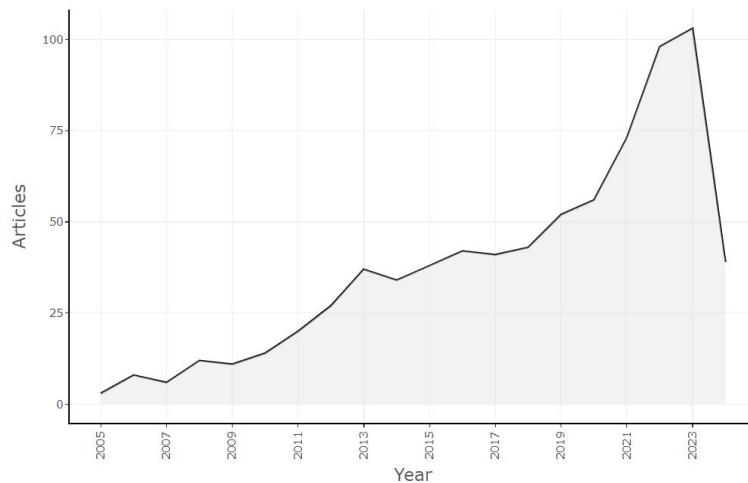
Figure 1 Annual Distribution of Scientific Production of Global Competence Studies (2005-2024)

4.2 Influential Global Competency Research

4.2.1 Most relevant sources

From 2005 to 2024, the academic discourse on GC is represented by 757 papers published across 223 sources. Applying Bradford's Law, the distribution of these papers reveals a three-zone stratification, reflecting the concentration of scholarly work in key journals. Zone 1, comprising a single journal, contributed 103 papers; Zone 2 accounted for 216; and Zone 3 encompassed 437 papers (excluding one retracted article). The top 10 source journals, listed in Table 2, contribute nearly one-third of the field's research, making them essential references for scholars.

Zone 1 journals, particularly "BMC Medical Education" (66 articles) and "Nurse Education Today" (37 articles), exert significant influence due to their high publication volume. Zone 2 journals sustain the research flow and broaden the discourse, while Zone 3 journals, though individually contributing fewer articles, collectively enrich the multidisciplinary nature of GC research. The prominence of "BMC Medical Education" and "Nurse Education Today" in Zone 1 highlights their pivotal role, yet their limited number underscores the need for researchers to also consider the top 10 journals, which collectively provide a more comprehensive view of the field.

Table 2 Most Relevant Sources of Global Competence Studies (2005-2024)

Journal	Rank	Numbers of Article	Zone
BMC Medical Education	1	66	1
Nurse Education Today	2	37	1
International Journal of Sustainability in Higher Education	3	22	2
Advances in Health Sciences Education	4	18	2
Academic Medicine	5	16	2
Journal of Studies in International Education	6	16	2
Language and Intercultural Communication	7	12	2
Medical Education	8	11	2

Compare: A Journal of Comparative and International Education	9	10	2
International Journal of Engineering Education	10	10	2

Table 2 highlights the significant concentration of GC research in medical and nursing education, reflecting the inherently global nature of healthcare. Journals such as "BMC Medical Education" and "Nurse Education Today" emphasize the development of GC in healthcare, focusing on cross-cultural communication, ethical decision-making, and international collaboration in medical practice and research[18-19]. These areas are central to preparing healthcare professionals for diverse settings.

GC research also spans disciplines such as language education, engineering education, and international education, underscoring its interdisciplinary relevance. In language education, journals like "Language and Intercultural Communication" highlight the role of language in fostering intercultural understanding[20-21]. Engineering education journals stress the need for engineers to address global challenges, work in multinational teams, and consider ethical implications in a global context[22]. International education journals explore how educational systems cultivate GC, preparing students to engage with global issues and diverse perspectives[23-24].

Influential sources of research on GC education, which span various subject areas, suggest that educators recognize the need for interdisciplinary professionals with a global mindset capable of navigating complex, interconnected global systems. This indicates that global competence is a multidisciplinary concept critical for a wide range of professionals in today's globalized world. Focusing on these influential journals can assist subsequent researchers by guiding their literature review process and providing an interdisciplinary perspective on GC research.

4.2.2 Most relevant authors and countries

This section analyses the most influential contributors in GC research, including authors, institutions, and countries, using quantitative metrics such as the h-index, g-index, m-index, total citations (TC), and number of publications (NP) to assess academic impact. Table 3 highlights the top authors ranked by NP, with Thomas, I., Brydges, R., Hu, J., Li, Y., and Mori, J. emerging as the most prolific. Their closely aligned NP reflects a competitive research environment. Notably, Brydges, R., Harendza, S.G., Barth, M., and Chiu, T.K.F. have exceptionally high TC, all exceeding 2000, with Brydges, R., focusing on GC in medical education, achieving a TC of over 7000. These metrics underscore their significant contributions to the field.

Table 3 The Most Relevant Authors

Rank	Author	h-index	g-index	m-index	TC	NP	Affiliation
1	Thomas, I.	19	36	0.67	1423	5	RMIT University
2	Brydges, R.	35	83	1.85	7011	4	Unity Health Toronto
3	Hu, J.	17	29	1.21	931	4	Zhejiang University
4	Li, Y.	9	15	1.00	269	4	Shanghai Normal University
5	Mori, J.	14	27	0.54	813	4	University of Wisconsin-Madison
6	Alsharif, N. Z.	19	30	0.63	1001	3	Lebanese American University
7	Barth, M.	26	51	1.50	2824	3	Eberswalde University for Sustainable Development
8	Brown, L.	15	22	1.00	588	3	Monash University
9	Chiu, T.K.F.	27	49	2.45	2534	3	Chinese University of Hong Kong
10	Harendza, S.G.	32	55	1.07	3684	3	Universitätsklinikum Hamburg-Eppendorf

Table 4 ranks authors by h-index, highlighting Brydges, R., Harendza, S., and Chiu, T.K.F. as particularly influential. Brydges, R. leads with the highest g-index (83) and m-index (1.85), while Harendza, S. and Chiu, T.K.F. also demonstrate strong academic presence with g-indexes of 57 and 49 and m-indexes of 1.07 and 2.45, respectively. These metrics provide a nuanced assessment of impact: the h-index measures consistent citation influence, the g-index emphasizes highly cited papers, and the m-index adjusts for career length by dividing the h-index by years since the first publication[25]. Combining these indices, Chiu, T.K.F. and Brydges, R. emerge as particularly impactful, with their work likely more focused and influential among the top authors.

Table 4 The Most Influential Authors

Rank	Author	h-index	g-index	m-index
1	Brydges, R.	35	83	1.85
2	Harendza, S.	32	57	1.07
3	Chiu, T.K.F.	27	49	2.45
4	Barth, M.	26	51	1.50
5	Thomas, I.	19	36	0.67
6	Alsharif, N. Z.	19	30	0.63
7	Hu, J.	17	29	1.21
8	Brown, L.	15	22	1.00
9	Mori, J.	14	27	0.54
10	Li, Y.	9	15	1.00

Chiu's research focuses on developmental models in GC, particularly emphasizing technology competencies such as AI and digital literacy. His work highlights the importance of integrating these skills into educational frameworks to prepare individuals for a digitalized, interconnected society[26-27]. This topic is highly relevant due to rapid digital transformation across industries and the growing demand for expertise in AI and digital technologies. Chiu's

exploration of effective strategies for cultivating these skills addresses the needs of the 21st-century workforce, making his work widely cited and influential. Its interdisciplinary nature, bridging education, technology, and global research, further enhances its appeal and applicability across fields. As AI advancements increase expectations for global competence, Chiu's research provides timely models and strategies, making it a critical resource for addressing contemporary educational challenges.

Brydges' research examines pedagogical strategies in medical education, emphasizing critical thinking, empathy, and intercultural awareness as essential components of GC for medical students[28-29]. Given the global nature of healthcare, which requires coordinated international responses, Brydges' work resonates with medical professionals, educators, and policymakers. His interdisciplinary approach, integrating medical expertise with education, cultural studies, and ethics, reflects the growing interest in transdisciplinary research. Brydges' focus on GC development in medical education offers valuable insights for researchers exploring multidisciplinary methods.

Other influential authors, such as Thomas, I. and Mori, J., contribute to GC research in engineering and language education, exploring its connotations, developmental models, and effectiveness[30-31]. Their work provides additional perspectives for researchers investigating GC in these interdisciplinary fields. Collectively, these authors highlight the diverse and evolving nature of GC research, offering critical insights for addressing global challenges across disciplines.

4.2.3 Most relevant journal articles

The compilation of papers listed in Table 5 represents the most globally cited works in the field of GC studies, providing a wealth of influential research. The 10 highly cited articles cover topics in areas as diverse as medicine, language education, and new age literacy development. Notably, while two articles are dedicated to the study of language education, the remaining eight offer a diverse array of research perspectives within the domain of GC education, contributing to a comprehensive understanding of the field.

Table 5 Most Global Cited Documents of Global Competence Studies

Author (Year)	Title	Total Citations	TC Per Year	Normalized TC
Smith-Donald, R. et al. (2007)	Preliminary Construct and Concurrent Validity of the Preschool Self-regulation Assessment (PSRA) for Field-Based Research	323	17.94	4.59
Kramsch, C. (2014)	Teaching Foreign Languages in An Era of Globalization: Introduction	279	25.36	9.76
Park, J.S.Y. (2011)	The Promise of English: Linguistic Capital and the Neoliberal Worker in the South Korean Job Market	172	12.29	3.70
Gutiérrez, A. & Tyner, K. (2012)	Media Education, Media Literacy and Digital Competence	161	12.38	4.55
Wilkinson, T. J. et al. (2009)	A Blueprint to Assess Professionalism: Results of a Systematic Review	152	9.50	3.47
Drudy, S. (2008)	Gender Balance/Gender Bias: The Teaching Profession and the Impact of Feminization	148	8.71	3.22
Morais, D. B. & Ogden, A. C. (2011)	Initial Development and Validation of the Global Citizenship Scale	135	9.64	2.91
Albareda-Tiana, S. et al. (2018)	Implementing the Sustainable Development Goals at University Level	125	17.86	6.90
Area, M. & Pessoa, T. (2012)	From Solid to Liquid: New Literacies to the Cultural Changes of Web 2.0	123	9.46	3.47
Melby, M. K. (2016)	Beyond Medical "Missions" to Impact-Driven Short-Term Experiences in Global Health (STEGHs): Ethical Principles to Optimize Community Benefit and Learner Experience	122	13.56	6.64

The study by Kramsch and Park delves into the intricate relationship between language acquisition and the development of global competence[32-33]. They argue that the complexities of global interconnectedness necessitate a pedagogical approach that is reflective, interpretive, and politically conscious. In response to the challenges posed by globalization, Kramsch advocates for a re-envisioning of the traditional 'five C's' of language education—communication, culture, connectivity, comparison, and community—to encompass a broader spectrum of competencies essential in the global arena. Kramsch posits that the evolution of foreign language education should place a premium on fostering GC, which extends beyond linguistic proficiency to include critical engagement with cultural diversity, adept navigation of global networks, and the strategic use of technology to enhance cross-cultural understanding. Park's research complements this perspective by highlighting the dual role of English in GC—as both a linchpin for global interaction and a catalyst for social and economic advancement, albeit subject to the influence of market dynamics and power structures. Overall, these two articles emphasize that language learning is key to GC, and both exemplify the integration of GC with

interdisciplinary fields. The high citations and increased attention to articles on GC in language education also suggests that it is a focus of researchers' attention.

Highly cited works like Smith-Donald et al., with 323 citations, emphasize self-regulation in early childhood education, a key GC component. Gutiérrez and Tyner cited 161 times, stress media literacy's importance in a digitalized world. In healthcare, Wilkinson et al., cited 152 times, provide a framework for evaluating professionalism, crucial for GC in global health. Other notable contributions include Drudy's analysis of gender dynamics in teaching and Melby's ethical considerations in global health, collectively addressing themes like sustainable development, media literacy, and gender issues[34-38].

The corpus of highly cited literature on GC exhibits several distinctive characteristics. It spans a variety of disciplines, with education, language studies, and healthcare emerging as particularly influential. The prominence of these fields in the literature can be attributed to the inherently global nature of these professions, which demand a profound understanding of diverse cultural contexts and the capacity to function effectively within them. Secondly, the topics addressed in these articles—self-regulation, linguistic capital, media literacy, professionalism, and ethical considerations in global health—are central to the discourse on GC. These topics resonate with a broad academic audience, as they pertain to the essential competencies required for individuals to excel in our interconnected world. Furthermore, the methodological approaches employed in these studies, including systematic reviews, structural validations, and ethical analyses, exemplify a rigorous research methodology. This rigor enhances the credibility and impact of the findings, rendering these articles as valuable references for future research. The high citation counts of these articles also reflect their interdisciplinary relevance, with concepts such as self-regulation in early childhood education being pertinent to fields like psychology, sociology, and public policy, and media literacy to communication and information science.

According to the above tables, several research directions present themselves as deserving of future scholarly attention. The integration of technological and digital competencies into the framework of GC is one such area, given the escalating digitalization of global interactions. Additionally, the role of soft skills, such as adaptability and intercultural communication, in the development of GC warrants further exploration, particularly in professional settings. The assessment and cultivation of global competencies in non-traditional educational contexts, including online platforms and community-based initiatives, is another promising area for research. Moreover, the impact of globalization on marginalized communities and the potential of GC to foster social equity and inclusion represents an emerging and significant field of inquiry.

4.3 Core Terms and Themes in Global Competency Research

4.3.1 Co-occurrence network of keywords

A co-occurrence network analysis reveals the connections between frequently co-occurring keywords in documents, illuminating the thematic structure of research fields. This method identifies dominant keywords and their relationships, tracking thematic evolution over time. Figure 2's network illustrates such patterns within GC literature.

The network identifies eight distinct research streams:

Intercultural and Global Competence: Focuses on 'intercultural competence', 'education', 'global competence'.

Medical Education: Centers on 'medical education' and 'medical students'.

Assessment and Clinical Competence: Emphasizes 'assessment', 'clinical competence', 'simulation', and 'global health'.

Sustainable Learning: Addresses 'learning', 'sustainability', 'education for sustainable development', and associated concepts.

Professional Development: Concentrates on 'professional development' and 'teacher'.

Globalization and Multilingualism: Explores 'globalization' and 'multilingualism'.

COVID-19 and Teaching: Investigates 'covid-19' and 'teaching'.

Intercultural and International Citizenship: Includes 'competence', 'intercultural', 'study abroad', 'identity', 'intercultural communication', 'cultural', 'students', 'global citizenship', and 'international citizenship', with a focus on 'nursing'.
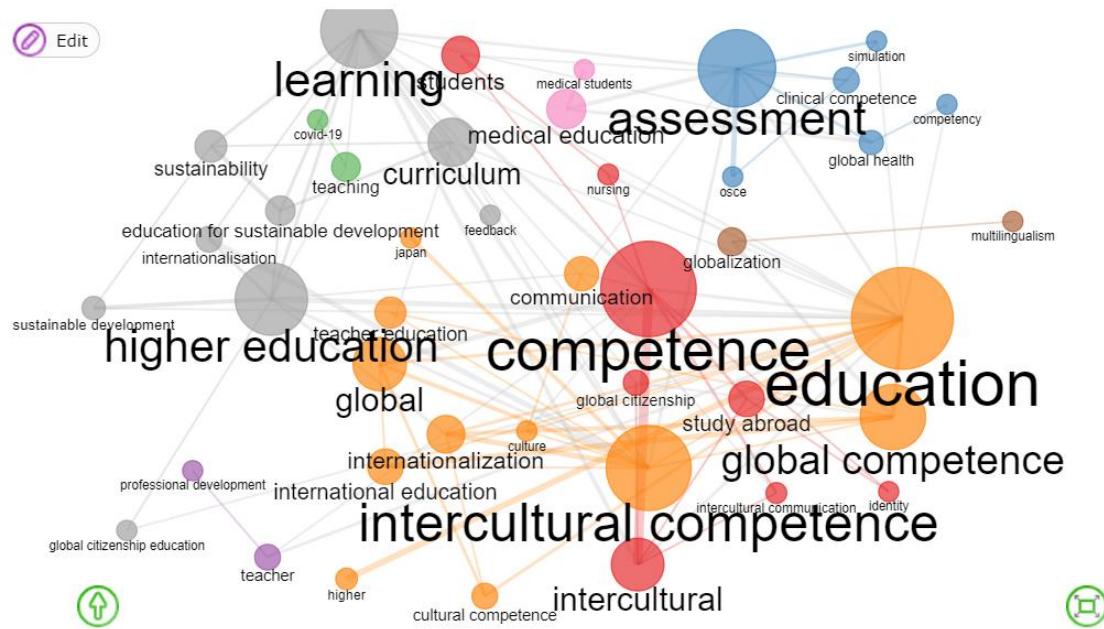
Figure 2 Co-occurrence Networks of Author's Keywords

The eight research streams in global competence (GC) literature can be grouped into four categories: Intercultural Competence and Communication, Educational Strategies and Professional Development, Globalization and Multilingualism, and Sustainability and Global Health.

The first and eighth streams fall under Intercultural Competence and Communication, emphasizing the importance of cross-cultural communication in navigating a globalized world. The first stream, highlighted in orange, focuses on foundational GC concepts like 'intercultural competence', 'education', 'culture', and 'global', stressing the need for effective communication and internationalization in education. Scholars such as Li and Schejbal and Irvine highlight the importance of intercultural skills for understanding diverse business cultures, political systems, and religious contexts, essential for success in international settings. The eighth stream, in red, integrates personal development, such as identity formation, with professional competencies, particularly in globally relevant fields like nursing[39-41].

The fifth stream, Educational Strategies and Professional Development, marked in purple, introduces 'professional development' and 'teachers', indicating a growing focus on educators' role in fostering GC. Research by Kerkhoff underscores the effectiveness of experiential learning and reflective practice in enhancing teachers' global competencies. Empirical studies, such as Parmigiani et al., show that improving teachers' GC positively impacts student development in this area, highlighting the need for continuous professional growth in intercultural and global skills.

The sixth research stream falls within the Globalization and Multilingualism category. The emphasis on multilingualism underscores the recognition that language proficiency is fundamental to accessing global knowledge and fostering intercultural dialogue. Research in this domain seeks to illustrate language skill development's critical role and effectiveness in nurturing GC.

The final category encompasses research streams 2, 3, 4, and 7, reflecting a significant body of work. The integration of sustainability and global health into the research streams indicates a shift towards considering the broader implications of global competence. This focus is particularly relevant in the face of shared global challenges such as pandemics, which necessitate collective and informed responses. The second research stream, in pink, centers on 'medical education' and 'medical students,' suggesting that the development of GC is integral to preparing future healthcare professionals for a diverse and globalized healthcare environment. The third stream, in blue, intertwines 'assessment,' 'clinical competence,' and 'simulation' with 'global health' and 'OSCE,' indicating a concern with evaluating clinical skills within the broader context of global health challenges. The fourth research stream, in grey, accentuates the imperative of equipping students to contribute to a sustainable future and to become responsible global citizens. The seventh research area, in green, addresses 'covid-19' and 'teaching and learning,' reflecting the impact of global crises on educational practice and the need for GC to encompass adaptability and response to unprecedented challenges.

4.3.2 Thematic map of global competence studies

In the realm of bibliometric analysis, thematic mapping serves as a critical tool for classifying and prioritizing research themes based on their relevance and centrality within a scholarly domain. Quadrant 1 (upper right) contains themes that are both highly relevant and central, indicating established areas of research with significant scholarly attention. Quadrant 2 (upper left) features themes that are relevant but not central, suggesting emerging areas that are gaining traction. Quadrant 3 (bottom left) includes themes of low relevance and centrality, often representing specialized or less explored areas. Quadrant 4 (bottom right) comprises themes that are central but less relevant, potentially indicating areas that are core to the field but are currently overlooked.

Based on the thematic map, it is evident that multilingual education and Covid-19, while significant, are currently niche research areas and do not rank highly in relevance. In contrast, GC research on themes such as globalization, education

for sustainable development, competency assessment, and the fields of medicine and global health are more mature, with a substantial body of literature and ongoing scholarly interest. Furthermore, in Quadrant 4, themes such as nursing competence and intercultural competence are identified as well-developed research areas. Conversely, teacher education appears to be an area currently less active, with a limited amount of mature research. Notably, the emergence of themes like translation and hiring in Quadrant 2 suggests potential new research trends that warrant further exploration.
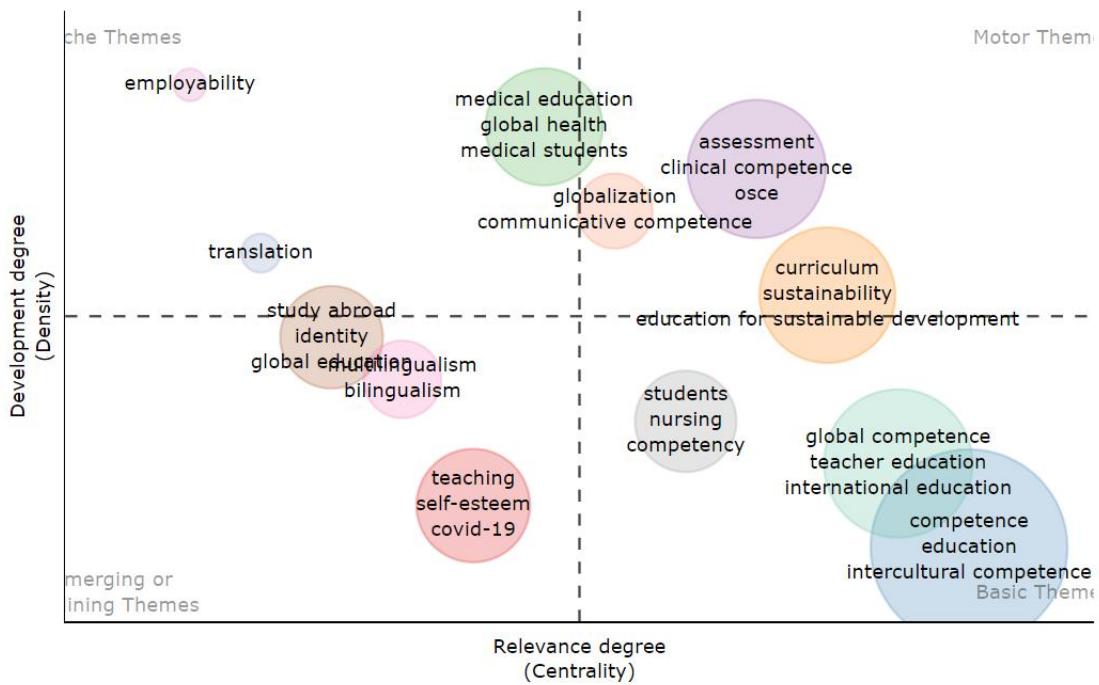
Figure 3 Thematic Map of Global Competence Studies

The synthesis of descriptive statistics and influential research points toward burgeoning avenues for future trends within the realm of GC. A prominent trend is the integration of technology and digital literacies into GC frameworks. This evolution is propelled by the digital transformation that is redefining the global landscape. As society becomes increasingly digital, there is a heightened demand for individuals capable of adeptly navigating, innovating, and leveraging digital tools. Digital fluency transcends technical proficiency, emerging as a pivotal element of GC that facilitates engagement with diverse communities and the resolution of complex, cross-cultural issues.

The role of soft skills, particularly adaptability and cross-cultural communication, is another area for further exploration. These soft skills are receiving escalating attention due to their documented impact on professional success and personal development within a globalized labor market. Adaptability equips individuals to flourish in volatile and unpredictable contexts, while cross-cultural communication fosters understanding and collaboration across diverse cultural landscapes. These abilities are fundamental to nurturing effective international partnerships and promoting mutual respect within our heterogeneous global society.

Additionally, the assessment and cultivation of global competence in non-traditional educational settings, such as online learning platforms, represents an emerging research domain. This inquiry is a response to the evolving educational paradigms and the burgeoning recognition that learning occurs in various environments beyond the traditional classroom. The exploration of global competencies in virtual spaces is essential for understanding how these competencies can be nurtured in the digital education era, catering to a diverse array of learners seeking to develop a global outlook.

The impact of globalization on marginalized communities and the role of GC in advocating for social equity and inclusion is also gaining traction as a significant research area. As global disparities become more pronounced, there is an urgent need for inclusive approaches to development. Globalization, if not managed equitably, risks exacerbating inequality. Research in this domain aims to uncover how GC can empower marginalized groups, level the playing field of opportunity, and champion social justice on a global scale.

Figure 3 illustrates additional trending research themes within the GC discourse, including employability and translation. Employability within the context of GC encompasses a spectrum of skills and attributes that enable individuals to contribute effectively to the global labor market. These include adaptability, problem-solving, and intercultural communication skills, which are increasingly valued as economies globalize. Educational institutions are thus incorporating GC into their curricula to prepare graduates for diverse work environments and to cultivate the global awareness vital for career success.

Translation is also a crucial component of GC, transcending its role as a language conversion tool to become a conduit for cultural exchange. It facilitates access to knowledge across linguistic barriers, deepening the understanding of diverse cultures and ideas. The demand for precise and culturally sensitive communication in sectors such as medicine,

law, and technology has surged, elevating the importance of translation skills. Moreover, the advent of machine translation and artificial intelligence technologies has catalyzed interdisciplinary research into how these advancements can complement human translation abilities, underscoring the dynamic and ever-evolving nature of translation in global communication.

5 CONCLUSION

This bibliometric analysis maps the global research landscape of GC, revealing a field of growing scholarly interest. Descriptive statistics indicate a significant increase in research output since 2005, underscoring the rising importance of preparing individuals for a complex global environment. The study highlights the multidisciplinary nature of GC research, spanning areas such as medical education, language pedagogy, and sustainable development, driven by international organizations, technological advancements, theoretical developments, and labour market demands. Analysis of influential authors and countries demonstrates global scholarly collaboration, with key contributors like Brydges and Chiu shaping the discourse through their focus on pedagogical strategies and technological competencies. Keyword co-occurrence networks identify central themes, including intercultural competence, educational strategies, globalization, and sustainable development, pointing to emerging research directions.

Future trends in GC research are expected to include the integration of digital and technological competencies, the role of soft skills in professional development, and the assessment of GC in non-traditional educational settings. Additionally, there is a growing focus on redefining traditional educational paradigms to incorporate global perspectives. The future of GC research will likely emphasize interdisciplinary approaches, engagement with technological innovations, and addressing the challenges of globalization.

The study has limitations, such as reliance on the Web of Science database, potential language bias, and a restricted timeframe. Future research should adopt more inclusive data collection methods, conduct longitudinal studies, and integrate quantitative and qualitative analyses to provide a comprehensive understanding of GC.

COMPETING INTERESTS

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

REFERENCES

[1] Ghosh B. The Collapse of the Soviet Union: Some Major Implications. India Quarterly: A Journal of International Affairs, 1996, 52(1-2): 1–14.
[2] Demir I, Canakci M, Egri T. Globalization and Economic Growth. Encyclopedia of the UN Sustainable Development Goals, 2021: 1–11.
[3] Steger MB. Globalization: A Very Short Introduction. Oxford: Oxford University Press, 2017.
[4] Robertson SL. Global Competences and 21st Century Higher Education – and Why They Matter. International Journal of Chinese Education, 2021, 10(1): 221258682110103.
[5] Volante L, Klinger DA. PISA, Global Reference Societies, and Policy Borrowing: The Promises and Pitfalls of 'Academic Resilience.' Policy Futures in Education, 2022, 21(7): 147821032110690.
[6] Donthu N, Kumar S, Mukherjee D, et al. How to Conduct a Bibliometric Analysis: An Overview and Guidelines. Journal of Business Research, 2021, 133: 285–96.
[7] Öztürk Ö, Kocaman R, Kanbach DK. How to Design Bibliometric Research: An Overview and a Framework Proposal. Review of Managerial Science, 2024.
[8] Guo J, Zhuang H, Howlader MH. Global Competence in Higher Education: A Ten-Year Systematic Literature Review. Frontiers in Education, 2024, 9.
[9] Fisher C, Hitchcock LI, Moak S, et al. Does Faculty-Led Short-Term Study Abroad Improve Students' Global Competence? Findings from a Systematic Review and Evidence Gap Map. Frontiers: The Interdisciplinary Journal of Study Abroad, 2023, 35(1): 417–52.
[10] Yari N, Lankut E, Alon I, et al. Cultural Intelligence, Global Mindset, and Cross-Cultural Competencies: A Systematic Review Using Bibliometric Methods. European J. Of International Management, 2020, 14(2): 210–50.
[11] Peng RZ, Zhu CG, Wu WP. Visualizing the Knowledge Domain of Intercultural Competence Research: A Bibliometric Analysis. International Journal of Intercultural Relations, 2020, 74: 58–68.
[12] Cretu DM, Morandau F. Initial Teacher Education for Inclusive Education: A Bibliometric Analysis of Educational Research. Sustainability, 2020, 12(12): 4923.
[13] Fischer JM, Mazurkiewicz G. The Personal, Place, and Context in Pedagogy: An Activist Stance for Our Uncertain Educational Future. Cham: Springer International Publishing AG, 2021.
[14] Li J. Comprehensive Global Competence for World-Class Universities in China. Springer Nature, 2019.
[15] Medhat A. A Critical Analysis to the United Nations' Performance in the Light of Contemporary Global Challenges. SSRN Electronic Journal, 2020.
[16] Ghironi F, Levchenko A. Globalization in the Aftermath of the Crisis. IMF Economic Review, 2018, 66(3): 415–17.
[17] Bump JB, Friberg P, Harper DR. International Collaboration and Covid-19: What Are We Doing and Where Are We Going? BMJ, 2021, 372(180): n180.

[18] Asampong E, Kamau EM, Tabong PTN, et al. Capacity Building through Comprehensive Implementation Research Training and Mentorship: An Approach for Translating Knowledge into Practice. Globalization and Health, 2023, 19(1).

[19] Nagy E, Luta GMM, Huhn D, et al. Teaching Patient-Centred Communication Skills during Clinical Procedural Skill Training - a Preliminary Pre-Post Study Comparing International and Local Medical Students. BMC Medical Education, 2021, 21(1).

[20] Jin TH. Moving beyond 'Intercultural Competence': Interculturality in the Learning of Mandarin in UK Universities. Language and Intercultural Communication, 2016, 17(3): 306–22.

[21] Martin JN, Nakayama TK. Reconsidering Intercultural (Communication) Competence in the Workplace: A Dialectical Approach. Language and Intercultural Communication, 2015, 15(1): 13–28.

[22] Ball AK, Zaugg H, Davies RS, et al. Identification and Validation of a Set of Global Competencies for Engineering Students. International Journal of Engineering Education, 2012, 28(1): 156–68.

[23] Gregersen-Hermans J. Toward a Curriculum for the Future: Synthesizing Education for Sustainable Development and Internationalization of the Curriculum. Journal of Studies in International Education, 2021, 25(4): 461–81.

[24] Sakamoto F, Roger P. Global Competence and Foreign Language Education in Japan. Journal of Studies in International Education, 2022.

[25] Eltorai AEM, Bakal JA, Kim D, Wazer D. Translational Radiation Oncology. Elsevier, 2023.

[26] Chiu TKF. A Holistic Approach to the Design of Artificial Intelligence (AI) Education for K-12 Schools. TechTrends, 2021, 65(5): 796–807.

[27] Chiu TKF, Falloon G, Song Y, et al. A Self-Determination Theory Approach to Teacher Digital Competence Development. Computers & Education, 2024: 105017.

[28] Gavarkovs A, Crukley J, Miller E, et al. Effectiveness of Life Goal Framing to Motivate Medical Students during Online Learning: A Randomized Controlled Trial. Perspectives on Medical Education, 2023, 12(1): 444–54.

[29] Sheikh N, Mehta J, Shah R, et al. Feedback That Lands: Exploring How Residents Receive and Judge Feedback during Entrustable Professional Activities. Perspectives on Medical Education, 2023, 12(1).

[30] Mori J, Takeuchi JD. Campus Diversity and Global Education: A Case Study of a Japanese Program. Foreign Language Annals, 2016, 49(1): 146–61.

[31] Thomas I, Michelsen G, Rieckmann M, et al. Routledge Handbook of Higher Education for Sustainable Development. London ; New York: Routledge, Taylor & Francis Group, 2018.

[32] Kramsch C. Teaching Foreign Languages in an Era of Globalization: Introduction. The Modern Language Journal, 2014, 98(1): 296–311.

[33] Park JSY. The Promise of English: Linguistic Capital and the Neoliberal Worker in the South Korean Job Market. International Journal of Bilingual Education and Bilingualism, 2011, 14(4): 443–55.

[34] Smith-Donald R, Raver CC, Hayes T, Richardson B. Preliminary Construct and Concurrent Validity of the Preschool Self-Regulation Assessment (PSRA) for Field-Based Research. Early Childhood Research Quarterly, 2007, 22(2): 173–87.

[35] Gutiérrez A, Tyner K. Media Education, Media Literacy and Digital Competence. Comunicar, 2012, 19(38): 31–39.

[36] Wilkinson TJ, Wade WB, Knock LD. A Blueprint to Assess Professionalism: Results of a Systematic Review. Academic Medicine, 2009, 84(5): 551–58.

[37] Drudy S. Gender Balance/Gender Bias: The Teaching Profession and the Impact of Feminisation. Gender and Education, 2008, 20(4): 309–23.

[38] Melby MK, Loh LC, Evert J, et al. Beyond Medical 'Missions' to Impact-Driven Short-Term Experiences in Global Health (STEGHs): Ethical Principles to Optimize Community Benefit and Learner Experience. Academic Medicine, 2016, 91(5): 633–38.

[39] Schejbal D, Irvine G. Global Competencies, Liberal Studies, and the Needs of Employers. Continuing Higher Education Review, 2009, 73: 125–42.

[40] Kerkhoff SN. Designing Global Futures: A Mixed Methods Study to Develop and Validate the Teaching for Global Readiness Scale. Teaching and Teacher Education, 2017, 65: 91–106.

[41] Parmigiani D, Bar Nir A, Ferguson-Patrick K, Forkosh-Baruch A, Heddy E, Impedovo MA, Ingersoll M, et al. Assessing the Development of Global Competence in Teacher Education Programmes: Internal Consistency and Reliability of a Set of Rubrics. Higher Education Pedagogies, 2023, 8(1).

FROM DUNHUANG TO THE SHAN HAI JING: ALGORITHMIC CULTURE FACILITATES CONTEMPORARY TRANSLATION OF CULTURAL HERITAGE AND THE RECONSTRUCTION OF ART DESIGN EDUCATION

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Abstract: This study proposes a dual-algorithm approach for integrating artificial intelligence into art and design education, combining a genetic algorithm and a cultural algorithm. We applied these methods in two pedagogical interventions focused on Dunhuang Murals and the Classic of Mountains and Seas (Shan Hai Jing). Using recursive generation and generative adversarial network (GAN) training, the genetic-algorithm pipeline preserved approximately 92% of traditional cultural symbols as measured by a symbol-matching metric. The cultural algorithm—designed to simulate sociocultural selection and incorporate iterative user-feedback—achieved an 88% symbol-matching rate and demonstrated positive cross-cultural reception in IP adaptation trials. These results suggest that algorithmic systems can function not only as technical tools but also as vectors for rematerializing cultural memory and accelerating cultural evolution. In light of these findings, contemporary art and design education should move beyond teaching tool use toward cultivating "digital humanists"—practitioners who can design, tune, and critically evaluate cultural algorithms.
Keywords: Genetic algorithm; Cultural algorithm; Dunhuang murals; Shan Hai Jing (Classic of Mountains and Seas); Art and design education; Cultural memory

1 INTRODUCTION

From the 1990s, algorithms that were seen as backend tools turned into core mechanisms to produce culture and disperse meaning. The advent of generative artificial intelligence technologies is transforming art and design fields in unprecedented ways. While the image generation and story generation technologies seem incredibly powerful, they also pose serious issues. The Western culture infused in Artificial Intelligence may tend to misrepresent non-Western culture systematically. Recent studies have reported high error rates, for instance, general AI tools misrepresent traditional Chinese visual features, reporting pattern errors ranging from 63% to 87%, particularly with regard to the Dunhuang murals, Shan Hai Jing, and the Miao batik. The reconstruction error rate of general AI for the above-mentioned visual elements is much higher than that of classical Western and modernist content. If measures are not implemented, this tech bias risks exacerbating a further erosion of cultural representation of Chinese heritage.

And today the art and design education paradigm cannot function with emulation-style apprenticeship anymore. This requires students to undergo such a large transformation, learning algorithm logic and cultural depth simultaneously, which can not only make Millennia-old patterns parameterization, but also fight against data hegemony at an ethical level.

The findings of its two longitudinal teaching experiments in our institution's digital AI workshop from 2023 to 2025 are:

"Contemporary Interpretation Project of Dunhuang Caisson Patterns" contributed to an innovative genetic algorithm method capable of preserving 92% of traditional cultural symbols through recursive generation, adversarial training, and mineral pigments' spectral mapping.

"The Global Recoding of Shanhaijing Mythological IP" developed a cultural algorithm which imitated the mechanisms of sociocultural evolution, achieved an 88% symbol match and cross-cultural acceptance. The system enabled up-to-date iteration using user heat maps and analysis over 30 international areas.

This research demonstrates that algorithmic systems are "programmable civilizations" rather than "destroyers" that can learn and form through education. In the critical approach, it aims at moving towards elevating algorithmics from technical means, and toward a cultural medium that encapsulates shared memory, incorporate normative ethics, and promotes cultural cultivation. So the point of contemporary art education and design is not simply to train students to work with AI, but to enable them to tune and critically assess the cultural algorithm. This will make the students not passive recipients of the age of the algorithm, but creative designers of culturally sensitive algorithms.

Three groups of key tensions can be countered by this research temp.

Between 92% precision and the 12% of an incalculable 'flash of insight'.

Between a global acceptance of 88% and indigenous cultural subjectivity.

Algorithmic automation and humanistic critique.

In the following two sections we analyze the principles, pedagogical strategies and educational impacts of genetic algorithms and cultural algorithms.

2 GENETIC ALGORITHM: INTEGRATION OF CULTURAL MATHEMATICS AND COMPUTING TECHNOLOGY IN ART AND DESIGN EDUCATION

The genetic algorithm that blends cultural mathematics with modern computer technologies offers a new perspective for contemporary art and design education. It facilitates tradition's cultural core with the new technology. Concurrently, this serves as both a precisely parameterized technical device and a powerful mechanism for remediating cultural memory in the digital realm. The recursive algorithm converts "three hares" patterns to symbols amenable to calculative and recursively expandable operations, breaking apart Buddhist reincarnation, cosmic cycles, and temporality. In other words, it translates the "stream of consciousness of inner time" of Husserl into the logic of the algorithm, keeping alive and reproducing ancient religious-aesthetic experiences in modern code[1-2].

2.1 Teaching Reconstruction under the Phenomenological Lens

In the present study, selected Dunhuang caisson ceiling patterns have been translated using a combination of algorithm and Colored patterns: three hares, flame pattern, lotus position and honeysuckle design patterns. The Samsara, Mandala-style symmetrical aesthetics, the golden ratio, and the spectral gradient of mineral pigments were accurately depicted by the recursive algorithm. Furthermore, 92% of the cultural symbols were retained following iterative optimization and GAN training[3]. Drawing on Merleau-Ponty's concept of the "body schema", this approach extends embodied perception to digital interfaces, whereby touching screens, motion capture, gesture recognition, and even VR equipment, students can control Genetic Algorithms and, via this change, create cross-temporal perceptual resonance with the Dunhuang artisans of a millennium ago, in response to subtle changes such as finger swipes, gestures in the air and body postures. As a result, this multi-modal experience visual, tactile, kinesthetic, and spatial perception integrates the body and technology, ancient and contemporary, of matter and digital code[4].

In hermeneutic circle this pattern translation process is precisely a dynamic practice of Gadamer's "fusion of horizons" (Gadamer, 1960/2004). The students in this context come to understand ancient craftsmen's cosmology, views on reincarnation, and visions of liberation as they face the limitations due to the cave environment in dim lighting, mineral pigment, and religious ritual. Subsequently, they transform this tacit knowledge into computable recursive functions, parametric curves, generation and color mapping rules, employing contemporary algorithmic reasoning. This dialogue is bidirectional, facilitating connections across everything, all times, cultures, and paradigms. The process suggests that tradition represents a dynamic body of knowledge that can be reactivated, reinterpreted and revitalized today.

From the perspective of the ontology of education, the genetic algorithm classroom is an experimental field and a growth space in the cultural psychology theory of Jerome Bruner. It's no longer just a teaching-only classroom where they teach some technical skills. The emphasis of today's teaching, however, lies in nurturing the cultural-psychological profile of the students. By being involved in Dunhuang pattern translation projects, students master advanced technologies like recursive generation, parametric modelling, generative adversarial training and color spectral mapping. This involvement fosters an ongoing conversation with norms that are over a thousand years old, often involving trial and error and empathetic engagement. This produces peculiar cultural psychological patterns, aesthetic judgment, and identities, which in turn moves cultural transmission from external indoctrination into internal generation[5].

2.2 Educational Enlightenment from Cultural Topology

The 92% symbol retention rate shows the genetic algorithm's educational value using Deleuze and Guattari's (1987 A Thousand Plateaus) topological perspective[6]. Algorithmic delocalization frees patterns from their material carriers—cave murals and fabrics—allowing them to flow freely and recombine iteratively in smooth space. Parametric modeling reconstitutes striated space on top of smooth space, transforming line directions, color hierarchies, symmetry relationships, and scale rules into precisely controllable, real-time adjustable, and cross-media migratable design parameters. Based on student-led variation and lines of flight experiments facilitated by algorithms, they generate artworks that are not carriers of meaning; they retain deep structures of cultural symbols while breaking away from traditional aesthetic frameworks, facilitating the development of experimental spirit, critical thinking, and creative imagination.

From the perspective of Jan Assmann's theory of cultural memory, the pedagogical process establishes a three-level chain[7]. The storage memory activates learners' historical cognition of religious metaphor and zeitgeist through a repository of cultural symbols (such as the Dunhuang pattern semiology and mineral pigment spectrum). This enables the generation of rules in dynamic grammars that can be programmed with a recursive algorithm (such as the parametric cloud pattern generator and the recursive function for the hui-pattern). communication memory facilitates the reconstruction of contemporary cultural and spatial effects through human-machine collaborative (such as the AR pattern co-creation platform and the cloud-based collaborative design space) interface.

In this way, from the perspective of Paulo Freire's critical pedagogy[8], these three progressive stages develop critical cultural awareness: In the Conscientization stage students analyze the constitutive principles and historical context of the Pantone color system thereby uncovering the underlying Western aesthetic hegemony and cultural centralism. The practical stage manifests tensions between local mineral pigments and Western industrial color systems, applied according to the stringent $\Delta E \leq 3$ standards, represents a technical negotiation of cultural sovereignty in parameter tuning[9]. In the dialogic stage, it visually presents the acceptance and emotional responses to the same artwork in a

cross-cultural environment through heat maps. In this they will learn to reach minimal agreement amid differences, enabling students to negotiate while preserving co-creation. According to this triple pathway, Assmann's theory is utilized as a longitude and Freire's pedagogy as latitude in cognition, technology, and ethics. This supports students to transition from being passive recipients to active producers of meaning. It supports the values of "truth, goodness, and beauty" in the context of algorithmic abundance, revitalizing millennia-old patterns in the digital world.

Benjamin's concept of the "aura" in the Age of Mechanical Reproduction" could benefit from a genetic-algorithm upgrade, which suggests a partial restoration of the aura with 92% symbol retention[10]. Meanwhile, Adorno's critique of the culture industry calls for vigilance and critical thought to prevent culture from becoming a ruling object or a homogeneous commodity under the logic of the algorithm[11]. Building on this, Pierre Nora's theory of "lieux de mémoire" positions digital education platforms with algorithmic library systems that position Dunhuang manuscripts as repositories of enduring archival memory. Through pattern translation projects, immersive exhibitions, co-creation workshops, and more, the classrooms reconstruct the memory of rituals of cultural heritage. Students' design work utilizes algorithmic variation and transforms them into counter-memories and cultural antibodies against global sameness and algorithmic hegemony[12].

3 CULTURAL ALGORITHM: INTELLIGENT OPTIMIZATION SIMULATING HUMAN SOCIETY'S CULTURAL EVOLUTION IN ART AND DESIGN

In fields like art and design education, the use of cultural algorithms injects unparalleled life, strength, and impetus to respond to the cultural change in human society. A teaching project involving the IP translation of the Classic of Mountains and Seas led Generative Adversarial Networks (GANs) to construct contemporary public art objects, interactive media, and urban layouts following Classic myths like "Jingwei Filling the Sea," "Kuafu Chasing the Sun," and "Gonggong Butting the Mountain" successfully. They had also achieved an 88% performance in cultural symbol matching rate, narrative fit, and cross-cultural acceptance. The genius of cultural algorithms to come up with ideas, carry out culture transmission and global communication.

3.1 Cognitive Philosophy Critique on Cultural Evolution

The Shanhaijing Project brings to light philosophical contradictions and tensions in multiple cognition in the cultural evolution of the algorithm era. The heat map, offering real-time cross-cultural feedback, is a perfect tool for transforming aesthetic assumptions, as well as subjective beliefs, into data-falsifiable, iteratively updatable objects. This suggests that cultural translation can transform from elite speculation and subjective interpretation into a data-informed, continuously evolving object of empirical research. Merging the Post-traditional aesthetic paradigm and visual styles from the West, the 88% symbol matching rate develops a novel visual grammar and narrative logic that fosters global dialogue and cross-cultural resonance[13]. Cultural algorithms are stripped away by the mechanism of 'natural selection' and reorganized by communication efficiency, emotional arousal, and commercial value parameters. Through the seemingly objective algorithmic "logic", a new power of knowledge reconstruction emerges — quietly dispelling, resetting, and reproducing the interpretive power of traditional myths and their cultural subjectivity[14].

3.2 Educational Construction of Ethical Topology

Levinas's own "philosophy of the Other" stresses the responsibility to the Other is infinite: it must be taken personally. It re-affirms the calls for presence in being in a confrontation with the Other. It rises above the self toward the Other in terms of needs. This transformation of the digital cultural heritage has been a four-dimensional matrix of responsibility[15]:

(1) The respect for tradition is fulfilled by a set of cultural taboos, which are like a historical firewall, protecting against the desecration of certain symbols.

(2) A contemporary response is embodied through a real-time verification system, akin to an 'ethical probe', in order to establish an 'ethical pause' which sharpens students' judgment in unique situations.

(3) The future responsibility emerges from an entropy detector, which measures the cultural diversity and complexity of the work, which helps students move away from their short term perspectives and take responsibility towards the broader goal of what they would contribute to the long term gene pool of civilization.

(4) Respect for the Other is manifested by a cross-civilizational heat map breaking the illusion of 'universal aesthetics'. It invites students to use concrete, diverse, and irreducible cultural "visages". Furthermore, learning to understand the rationality of the Other's logic within difference.

This matrix is what the student uses to see and take responsibility for those other than themselves and is therefore the door to the realization of the conditions for dialogical translation through technology and dialogue, regarding the civilized way, and for sustainable evolution.

Hegel's thesis-antithesis-synthesis dialectic gives a straightforward teaching structure[16]: within 72 hours, GANs can generate hundreds of visual prototypes and interactive scenes from the symbols of "Shan Hai Jing", effectively breaking time, skill, and imagination barriers of traditional design[17]. The CLIP multimodal model has a semantic departure of 0.15. It sometimes gives rise to blind spots in the algorithms due to a lack of understanding of the deeper cultures, or being blind to taboos or context sensitivity. Left unchecked, it may result in blasphemous use of symbols, creating

stereotypes, and cultural appropriation, and so on. It occurs through the students' critical revision, facilitated over many rounds of cultural decoding-ethical reflection-meaning reconstruction-form adjustment, with the result that expressions with a cultural basis, contemporary in nature, can be formulated with a capacity to engage in conversations around global issues occurring in the context of technology-related crises.

Intercultural competence, as the Core Competences in Digital-age, formed through a framework of three levels. In the cognitive layer, the course "Critiques of Said's Orientalism" allowed students to study and analyze the identification and deconstruction of algorithmic outputs based on geographic, gender, and power biases[18]. According to theory of communicative action, the ethical dimension attending responsibility attribution, empathetic understanding, and negotiated consensus building in heat map difference networks[19]. Finally, informed by dialogic theory, the creative layer must be prepared to develop the 'translation interface,' wherein mythological fragments are reorganized for different users. These interfaces help create 'third spaces' to respond to different cultural manifestations.

To protect 12% cultural heterogeneity, Adorno's negative dialectics draws on the philosophy of non-identity. It is a necessary tool, since 88% is matching. Therefore, it follows that minimal morality and maximal respect form key moral education practices of the cultural algorithm[20]. It delivers $\Delta E \leq 3$ standards. John Durham Peters's elemental media theory allows for a four-dimensional experience of new design subjects– Earth (the digital compiling of rooted cultural genes, e.g., Miao batik parametric modeling), fire (the creative destruction by GANs, e.g., humanistic intervention of Xingtian images), air (meaning perception in global fluctuations through heat maps, e.g., Dunhuang Feitian hierarchical optimization), and finally water (the adaptive shaping of carry-cross-border collaborations, e.g., silk road hybrid patterns). So students can become new humanists who protect humanistic constellations in algorithmic jungles and tame technology with humanistic reason[21].

4 CONCLUSION: CIVILIZATIONAL NERVE ENDINGS IN THE ALGORITHMIC ERA

Art and design education is increasingly the place where human culture stays alive and keeps making sense in an algorithmic world. Indeed, genes and culture now rely on algorithms to pass down, store, and evolve collective memory. As a result, cultural ideas now evolve faster through real-time feedback and global collaboration, thereby pushing art and design education to focus less on preserving skills and more on training creators who can code, design, troubleshoot, and think critically about culture's algorithms. Algorithms have finally managed to turn the kind of hands-on know-how that craftsmen never write down into something that can actually be measured, shared, and reused across different fields through neural networks. All this is now possible with motion capture, eye-tracking, muscle sensors, neural networks, and various related technologies. In the end, it establishes a real, working bridge for passing craft knowledge across cultures, generations, and media.

The aims of art and design education are dedicated to cultivating digital humanists who have the ability to master advanced algorithmic technologies while upholding the depth and diversity of culture. A global heat map reveals that the world is in a state of dynamic interconnection, and human society has reached high interconnectivity, particularly in the digital age. Thousands of years of painting and calligraphy still resonate when we encode them into computer code. That's precisely what digital humanists do, mixing code with traditional signs and symbols, bringing old practices back to life on screen, and allowing today's workers to design new work to keep it diverse and impossible to condense to a single meaning, all of it distributed through algorithms. Indeed, that is precisely what contemporary art and design education must do today — and may very well determine whether human civilization can survive, evolve, and start over in the digital age.

COMPETING INTERESTS

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REFERENCES

[1] Husserl E. The phenomenology of internal time-consciousness. Indiana University Press, 2019. https://doi.org/10.2307/j.ctvh4zhv9.7.

[2] Bogotá J D, Djebbara Z. Time-consciousness in computational phenomenology: A temporal analysis of active inference. Neuroscience of Consciousness, 2023(1). https://doi.org/10.1093/nc/niad004.

[3]   Yu T, Lin C, Zhang S, et al. Artificial intelligence for Dunhuang cultural heritage protection: the project and the dataset. International Journal of Computer Vision, 2022, 130(11): 2646-2673. https://doi.org/10.1007/s11263-022-01665-x.

[4]   Merleau-Ponty M, Landes D, Carman T, et al. Phenomenology of perception. Routledge, 2013. https://doi.org/10.4324/9780203720714.

[5]   Mattingly C, Lutkehaus N C, Throop C J. Bruner's search for meaning: A conversation between psychology and anthropology. Ethos, 2008, 36(1): 1-28. https://doi.org/10.1111/j.1548-1352.2008.00001.x.

[6]   Deleuze G. Difference and repetition. Columbia University Press, 1994. https://doi.org/10.5040/9781350250291-0060.

[7]   Assmann J. Cultural memory and early civilization: Writing, remembrance, and political imagination. Cambridge University Press, 2011. https://doi.org/10.4102/nc.v68i0.273.

[8]   Freire P. Pedagogy of the oppressed. In Toward a sociology of education. Routledge, 2020: 374-386. https://doi.org/10.4135/9781483318332.n282.

[9]   Sharma G, Wu W, Dalal E N. The CIEDE2000 color‑difference formula: Implementation notes, supplementary test data, and mathematical observations. Color Research & Application: Endorsed by Inter‑Society Color Council, The Colour Group (Great Britain), Canadian Society for Color, Color Science Association of Japan, Dutch Society for the Study of Color, The Swedish Colour Centre Foundation, Colour Society of Australia, Centre Français de la Couleur, 2005, 30(1): 21-30. https://doi.org/10.1002/col.20070.

[10] Benjamin W. The work of art in the age of mechanical reproduction. In A museum studies approach to heritage, Routledge, 2018: 226-243. https://doi.org/10.4324/9781315303673-16.

[11] Horkheimer M, Adorno T W, Noeri G. Dialectic of enlightenment. Stanford University Press, 2022. https://doi.org/10.1515/9780804788090.

[12] Nora P. Between memory and history: Les lieux de mémoire. representations, 1989: 7-24. https://doi.org/10.2307/2928520.

[13] Tutuncuoglu B T. Algorithmic Memory: How AI is Rewriting What Societies Choose to Remember or Forget. Available at SSRN 5271673, 2024. https://doi.org/10.2139/ssrn.5271673.

[14] Wut T M, Lee D, Ip W M, et al. Digital sustainability in the organization: Scale development and validation. Sustainability, 2021, 13(6): 3530. https://doi.org/10.3390/su13063530.

[15] Johnson M, Bradley L. Essays as "clinical" pedagogy: a Hegelian approach to essay writing. The Law Teacher, 2024, 58(4): 515-534. https://doi.org/10.2139/ssrn.5114797.

[16] Goodfellow I J, Pouget-Abadie J, Mirza M, et al. Generative adversarial nets. Advances in neural information processing systems, 2014, 27. https://doi.org/10.1007/978-3-658-40442-0_9.

[17] Schaefer M, Heinze H J, Rotte M, et al. Communicative versus strategic rationality: Habermas theory of communicative action and the social brain. PloS one, 2013, 8(5): e65111. https://doi.org/10.1371/journal.pone.0065111.

[18] Callinicos A, Kouvelakis S, Pradella L. Routledge handbook of Marxism and post-Marxism. New York: Routledge, 2021. https://doi.org/10.4324/9781315149608.

[19] Yamamoto J, Ananou S. Humanity in digital age: Cognitive, social, emotional, and ethical implications. Contemporary Educational Technology, 2015, 6(1): 1-18. https://doi.org/10.30935/cedtech/6136.

[20] Striphas T. Algorithmic culture. European journal of cultural studies, 2015, 18(4-5): 395-412. https://doi.org/10.1177/1367549415577392.

[21] Cadi Yazli N, Baka E, Magnenat-Thalmann N, et al. Modeling craftspeople for cultural heritage: A case study. Computer Animation and Virtual Worlds, 2022, 33(3-4): e2075. https://doi.org/10.1002/cav.2075.

DEVELOPMENT OF OPEN ONLINE COURSES AND BLENDED TEACHING PRACTICES FOR POSTGRADUATE EDUCATION IN THE ERA OF ARTIFICIAL INTELLIGENCE: EVIDENCE FROM THE COURSE "STATISTICAL ANALYSIS AND SOFTWARE APPLICATIONS"

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Abstract: Rapid advancements in artificial intelligence (AI) are fundamentally reshaping postgraduate education and imposing new demands on methodology-oriented courses. Using the core postgraduate course Statistical Analysis and Software Applications as a case, this study investigates the development of open online courses and AI-enabled blended teaching practices within the framework of competence-oriented education reform. First, a multidimensional competency profile is constructed to reconceptualize course objectives, emphasizing data literacy, research competence, software proficiency, and responsible AI use. Second, an integrated framework for open online course development is proposed on the Rain Classroom platform, which integrates diverse learning resources, explicit norms for AI use, and data driven instructional support. Third, an AI-enabled blended teaching model that integrates pre-class online learning, in-class interaction, and post-class research tasks is designed to facilitate problem-driven and project-based learning. Finally, a diversified and intelligent assessment system that combines formative evaluation, course papers, and learning analytics is established. The findings indicate that the proposed approach effectively enhances students' statistical thinking, software application skills, and research capabilities and provides a scalable reference for methodological course reform in the AI era.

Keywords: Artificial intelligence; Postgraduate education; Blended learning; Open online courses; Statistical methodology

1 INTRODUCTION

The rapid development of artificial intelligence (AI), big data, and the digital economy is reshaping the objectives and implementation pathways of postgraduate education [1]. In fields such as economics, management, and applied statistics, statistical analysis is no longer limited to understanding and manually deriving classical models. Instead, it is closely linked to competencies in multisource data processing, the integrated use of statistical software, and intelligent tool-assisted decision-making. Postgraduate students increasingly rely on statistical software such as Stata, R, and Python, as well as AI-based tools for literature retrieval, code generation, and text editing in their research and academic writing [2]. However, without solid training in statistical thinking and methodology, the mechanical use of software or excessive reliance on "AI-generated outputs" may compromise research quality and pose risks to academic integrity and technological ethics [3]. In the era of AI, systematically enhancing postgraduate students' data literacy, software application skills, and research competence through curricular reform has emerged as an urgent issue for higher education institutions.

The advancements in "Internet + Education" and "AI + Education" have created new opportunities for reform in postgraduate curricula. Compared with undergraduates, postgraduate students differ substantially in terms of learning content complexity, levels of learning autonomy, and research orientation [4]. These characteristics imply that open online courses for postgraduate education cannot merely replicate general-purpose MOOC models; rather, they require more targeted designs in terms of course objectives, resource formats, interaction modes, and evaluation mechanisms. Accordingly, the development of high-quality open online courses should move beyond a single format of recorded lectures and uploaded videos toward an integrated instructional design encompassing objectives, content, resources, and data. This approach aims to build a comprehensive learning environment that supports self-directed learning, discussion-based interaction, and research training, thereby enabling coherent integration of online and offline instruction.

Statistical Analysis and Software Applications is a core methodological course offered by Zhengzhou University of Aeronautics for postgraduate students in economics, management, engineering, statistics, and related disciplines. It plays a foundational role in developing students' proficiency in quantitative research tools and their capacity to conduct empirical analysis. However, existing teaching practices still face several challenges, such as insufficient integration between theoretical instruction and software-based practice, limited alignment between course cases and students' actual research topics, fragmented and outdated learning resources, and inadequate use of learning process data. As a result, students often "learn many methods and master a number of commands" but struggle to apply this knowledge to

concrete research contexts and have a limited understanding of the appropriate role of AI tools in data analysis and academic writing. The recent approval of a postgraduate high-quality open online course development project, supported by the Rain Classroom platform, has provided a valuable opportunity to systematically promote the online openness and blended teaching reform of *Statistical Analysis and Software Applications*.

Against this background, this study focuses on the development of open online postgraduate courses and blended teaching practices in the era of AI, with statistical analysis and software applications as representative cases. It focuses on four key research questions. First, in the context of AI extensively empowering research and learning, how should postgraduate statistics-related courses define students' competency profiles and accordingly reconstruct course objectives and content structures? Second, how can online platforms be leveraged to develop course websites that have clear structures, abundant resources, a strong AI orientation, and comply with the standards for high-quality open online courses? Third, how can an integrated "pre-class, in-class, and post-class" blended teaching model be designed in contexts involving AI tools to balance knowledge acquisition, methodological application, and research training? Finally, how can learning behavior data, online assignments, and course papers be used to construct a diversified and intelligent evaluation system that integrates both formative and summative assessments?

2 LITERATURE REVIEW AND MARGINAL CONTRIBUTIONS

2.1 Research on Postgraduate Curriculum Reform

Mainstream trends in international postgraduate education reform indicate that the systematic reconstruction of competence development pathways has reached a global consensus, reflecting a fundamental shift from a teaching paradigm centered on knowledge transmission to one oriented toward competence construction. In this process, the principles of competency-based and outcome-oriented education have been widely adopted, which requires curriculum design to move beyond content coverage and toward the deliberate structuring of pathways for competence attainment [5]. Existing international experiences can be categorized into three representative models. First, project-based learning emphasizes learning in authentic contexts to facilitate interdisciplinary collaboration, thereby enabling students to develop research, communication, and teamwork skills through integrated tasks [6]. Second, problem-based learning promotes students' active construction of knowledge by embedding learning in complex problem contexts, thereby fostering critical thinking and independent problem-solving abilities [7]. Third, seminar-based teaching highlights the co-construction of knowledge and fosters the development of research awareness through intensive discussion and reflection [8]. Although these models have been supported by relatively mature institutional arrangements and practices across countries, substantial differences persist in competence assessment approaches, task-chain designs, and learning support systems, suggesting that they are not universally applicable, one-size-fits-all solutions [9].

Scholars in China tend to emphasize the local adaptability of institutional contexts and training objectives in discussions of postgraduate curriculum reform, and their research has focused primarily on the structural optimization of curriculum systems, the dynamic updating of teaching content, and the innovative application of instructional methods. Among these, methodology-oriented courses have attracted more attention because of their foundational role in cultivating research capabilities [10]. Existing studies suggest that the value of reforming such courses lies primarily in shifting from a knowledge-delivery model to a research-training model, thereby restructuring the learning process through practice-oriented and open-ended tasks [11]. However, the literature presents a clear pattern of well-articulated concepts but insufficient operationalization. Most studies remain largely at the level of articulating reform principles and offer limited in-depth analysis of key issues, such as how to construct competence-oriented curriculum objectives, how to integrate specific instructional platforms into an overall course design, and how to use process data to evaluate teaching effectiveness.

Overall, although the existing studies have converged in their general orientations, systematic research on the reform of specific methodology-oriented courses remains insufficient, leaving pronounced gaps in operable design under a competence-oriented framework and in empirically grounded effectiveness evaluation. These gaps constitute critical challenges that future research must address.

2.2 Research on Open Online Course Development

In recent years, the emergence of MOOCs, SPOCs, and high-quality open online courses at multiple levels has created important opportunities for the digital transformation of postgraduate education [12]. Existing studies largely concur that open online courses can overcome temporal and spatial constraints, expand learning spaces, and facilitate instructional diagnosis and continuous improvement through platform-generated data [13]. Building on this foundation, prior research has sought to characterize high-quality online courses across multiple dimensions, including course objectives, knowledge unit structures, resource diversity, and learning support services [14]. However, much of the existing research shows a tendency to merely list features, emphasizing which elements should be included while paying limited attention to how these elements operate synergistically or contribute to verifiable learning outcomes.

In the field of postgraduate education, recent discussions have increasingly focused on integrating research activities into the course process to better support the development of core postgraduate competencies [15]. These activities include literature review, research design, and data analysis. While these studies offer clear directions for developing online courses in postgraduate education, they often remain at the level of normative advocacy and lack mechanism-based analyses grounded in specific course contexts. For example, the literature rarely examines how task

chains can be constructed around research-oriented objectives, how platform functionalities support the development of research skills [16], or how online and offline components can be effectively coordinated within blended learning environments [17]. Methodologically, the current research also has notable limitations. Most studies largely rely on instructors' experiential reflections, with limited systematic analyses of learning data, interaction behaviors, or instructional experiments [18]. Additionally, insufficient attention has been given to aligning online platforms such as Rain Classroom within an integrated "objective-content-resources-assessment" framework. This has led to a disconnect between theoretical explanations and platform-based instructional practices [19].

Overall, although research on open online courses has generated a substantial body of conceptual work, there remains a pressing need to move beyond descriptive accounts of educational ideas towards the articulation of underlying mechanisms and the empirical testing of design-oriented propositions. Future research could draw on case studies, data-driven analyses, and instructional experiments to systematically examine how online courses contribute to the development of postgraduate students' research capabilities and to identify coherent pathways for optimizing platform-based instructional design.

2.3 Research on Blended Learning and AI-Enabled Instruction

Blended learning, which integrates the flexibility of online learning with the interactive advantages of face-to-face instruction, has become a major direction of reform in higher education [20]. Research generally indicates that this model enhances learner autonomy and higher-order cognitive and practical skills through face-to-face interaction [21]. In methodology-oriented courses, online micro-lectures are typically used to introduce concepts and foundational methods, whereas offline classrooms focus on theoretical derivation, case analysis, and software operation, thus forming a progressive structure from knowledge to skills and ultimately to application [22]. However, some studies have noted that the online and offline components are often fragmented, resulting in a lack of coherence in learning pathways and undermining the potential effectiveness of blended learning [23].

The rapid advancement of AI has further driven the evolution of blended learning models [24]. Learning analytics, intelligent recommendation systems, and automated assessment technologies have enhanced personalized learning support, enabling instructors to implement data-driven interventions based on learners' performance data [25]. Moreover, the application of large language models in literature retrieval, code debugging, data analysis, and writing assistance has reshaped how students engage in research activities [26, 27]. Some studies indicate that AI can improve learning efficiency by allowing students to allocate more effort to higher-order tasks, thereby aligning with the competency development objectives of methodology-oriented courses [28].

However, critical studies indicate that the convenience of AI tools may undermine students' independent thinking, problem formulation, and analytical reasoning, leading to an overreliance on technology [29, 30]. In addition, academic integrity risks linked to generative tools—such as the limited traceability of automatically generated code or text—present significant challenges for course assessment and the development of academic norms [31]. Consequently, scholars widely call for achieving a balance between technological empowerment and competency development by clarifying usage boundaries, strengthening normative guidance, and optimizing task design to ensure that students maintain an appropriate level of academic rigor while leveraging tools to improve efficiency.

Overall, although existing studies acknowledge the potential of integrating blended learning with AI, they remain largely descriptive and technology-oriented, lacking systematic examinations of pedagogical mechanisms and learning outcomes. This gap highlights the need for more in-depth practical and empirical research grounded in specific course contexts.

2.4 Potential Marginal Contributions

Compared with existing studies, our work makes two primary contributions.

First, we develop a competency profile for postgraduate statistics courses that is aligned with the demands of the AI era and propose a systematic reconstruction pathway that ensures coherence among learning objectives, course content, and learning tasks. Moving beyond the predominantly principle-based discussions of competency development in the literature, this study is, to our knowledge, the first to delineate learners' competency structures in methodology-oriented courses along three dimensions—data literacy, software proficiency, and research competence—and to translate these dimensions into an operationalized system of course objectives. Building on this framework, we reorganize course content through a multichain task-based structure encompassing theory, methods, software, and AI tools, thereby establishing a systematic, research-oriented instructional design logic that addresses the core demand for a competency-based transformation in postgraduate education.

Second, we propose a new blended learning model for postgraduate education in AI-participatory learning contexts and develop a verifiable framework for open online course construction and intelligent evaluation. Unlike much of the existing research, which remains at the level of technological description or platform-level application, we adopt Rain Classroom as the instructional platform and integrate open online course development, norms for AI tool usage, learning analytics, and formative assessment into a unified framework. By designing an integrated structure of pre-class self-study, in-class discussion, and post-class research, together with AI-assisted learning task chains, we achieve deep integration between online and offline learning environments. Moreover, we construct an intelligent and diversified evaluation system based on learning behavior data, online assignments, and research paper performance, thereby

providing a scalable model and empirical evidence to support the reform of methodology-oriented courses.

3 POSTGRADUATE COMPETENCY PROFILES AND COURSE OBJECTIVE RECONSTRUCTION IN THE ERA OF AI

Amid the rapid evolution of AI, postgraduate training objectives are increasingly shifting from traditional knowledge-acquisition models to problem-solving-oriented models. This trend is particularly evident in courses centered on statistical methods. Students are expected not only to master statistical techniques but also to understand their underlying theoretical logic, conditions of applicability, and normative requirements. This shift moves students beyond merely "knowing how to use" methods toward explaining results, exercising methodological judgment, and adhering to academic standards.

Drawing on the characteristics of disciplines such as economics, management, statistics, and engineering, we define the competency profile required for the course *Statistical Analysis and Software Applications* across four dimensions (see Figure 1). First, statistical thinking and problem-modeling capability enable students to formulate quantifiable research questions from real-world contexts and to understand the fundamental principles, underlying assumptions, and limitations of statistical inference and regression analysis. Second, the integrated application of statistical software allows students to conduct data import, cleaning, modeling, and visualization on platforms such as Stata, R, or Python, thereby establishing standardized and reproducible analytical workflows. Third, empirical research design and academic communication skills enable students to formulate sound research hypotheses based on systematic literature reviews, select appropriate statistical and econometric methods, and produce analytically rigorous, well-structured research reports or course papers. Fourth, the appropriate use of AI tools and awareness of technological ethics require students not only to employ AI tools to assist with literature retrieval, code verification, and result presentation but also to recognize their limitations and actively avoid potential risks of academic misconduct.

Figure 1 Four-Dimensional Postgraduate Competency Profile

Building on the competency profile, the course objectives are reframed away from a traditional focus on method mastery and software usage toward a multilevel objective framework. At the cognitive level, students are expected to comprehend the underlying logic, key assumptions, and applicability conditions of statistical and econometric methods. At the operational level, students are expected to demonstrate proficiency in the estimation, diagnostics, and extension of commonly used models. At the applied level, students are expected to independently complete at least one full empirical research project. At the reflective level, students are expected to critically evaluate the rationale for model selection, the robustness of the results, and the appropriate use of AI tools.

According to the competency profile and the objective framework, the course content shifts away from a traditional chapter-based organization toward a "modular and task-based" structure. Specifically, the course consists primarily of the following modules: data cleaning and descriptive statistics, statistical inference and regression analysis, practical statistical software application, appropriate use of AI in statistical analysis, and comprehensive projects and term papers. These modules not only ensure a logical progression of knowledge but also emphasize the gradual development of competencies, thus providing a solid foundation for the subsequent development of course resources and blended instructional design.

4 DEVELOPMENT OF OPEN ONLINE COURSE RESOURCES BASED ON RAIN CLASSROOM

The Rain Classroom was jointly developed by the Office of Online Education of Tsinghua University and XuetangX, with the aim of supporting the digitalization and intelligent transformation of the entire teaching process through information technology. Guided by the concept of "data-driven teaching", the platform optimizes the entire instructional chain by covering key stages such as pre-class preparation, in-class interaction, and post-class assessment. Its core technological architecture is built on an integrated architecture that combines a PowerPoint plug-in with mobile terminals. Instructors can directly embed exercises, videos, and other multimedia materials into PowerPoint slides and deliver them synchronously to students via WeChat. Students can participate in learning activities through WeChat or web-based interfaces, which enables cloud-based management of instructional resources and real-time collection of classroom behavioral data.

Built on the Rain Classroom platform, the overall design of the course website adheres to the principles of "clear structure, comprehensive functionality, and distinctive features". The website consists of several core modules, including the course overview, syllabus, lesson plans and courseware, guidance on key and challenging topics, online assignments and question banks, instructional videos, literature and extended resources, and guidelines for the standardized use of AI tools. The platform's integrated functions—such as attendance tracking, pop-up quizzes, discussion forums, and data analytics—provide strong technical support for the effective integration of online and offline instruction.

With respect to resource types and content development, the course prioritizes the following core resource types. First, textual resources—including the syllabus, detailed lesson plans, study guides, and practical laboratory manuals—are designed to provide students with a systematic learning pathway and clear operational guidance. Second, video resources include theoretical lectures, software operation demonstrations, and case studies. All videos are produced through high-quality classroom recordings or studio-based filming, with a total duration exceeding 300 minutes, which helps avoid the limitations of single-format PPT screen recordings. Third, data and case resources offer authentic datasets and accompanying demonstration codes on key topics in China's contemporary economic development, such as the digital economy, low-altitude economy, green development, and regional coordination. This approach encourages students to engage in extended inquiry beyond analytical replication. Finally, assignment and question-bank resources are structured hierarchically according to knowledge structures and competency levels, integrating practice exercises and project-based microtasks to foster both conceptual understanding and practical skills.

To emphasize the course's distinctive orientation toward the "AI era", a dedicated module on AI tools and their responsible use is introduced. This module systematically presents categories of AI tools relevant to statistical analysis and academic writing, their functional applications, and typical use scenarios while conveying the principle of "assistance rather than substitution" through short videos and practical demonstrations. Moreover, the course establishes explicit guidelines for AI use, specifying unacceptable practices such as data fabrication, result manipulation, and the direct adoption of AI-generated text. In project briefs and learning guides, students are expected to disclose their use of AI tools, thereby integrating technological application with instruction in academic integrity.

Furthermore, the course adopts a periodic evaluation mechanism that dynamically adjusts the resource structure and content quality based on student feedback and learning analytics. High-quality assignments and project outputs are anonymized and integrated into the resource repository, forming a virtuous cycle of "teaching-learning-resource regeneration" that continually enhances the adaptability and sustainability of course resources.

5 AI-ENABLED "ONLINE + OFFLINE" BLENDED TEACHING DESIGN

Building on the established teaching resources, the course is structured to develop an "online + offline" blended teaching model that integrates the pre-class, in-class, and post-class stages (see Figure 2). In the pre-class phase, instructors use Rain Classroom to deliver instructional videos, reading materials, and preparatory quizzes. This approach supports students in building foundational concepts and methodological frameworks, facilitating a shift from "passive reception" to "active preparation". During the in-class phase, offline instruction focuses on explaining key and challenging concepts, case studies, practical software operations, and group seminars. In addition, digital tools—such as attendance checks, pop-up quizzes, polling, and discussion forums—are used to enhance teacher–student interactions. In the post-class phase, online assignments, project-based tasks, and reflective learning logs are used to promote knowledge consolidation, transfer, and deeper understanding, contributing to a closed-loop learning process.
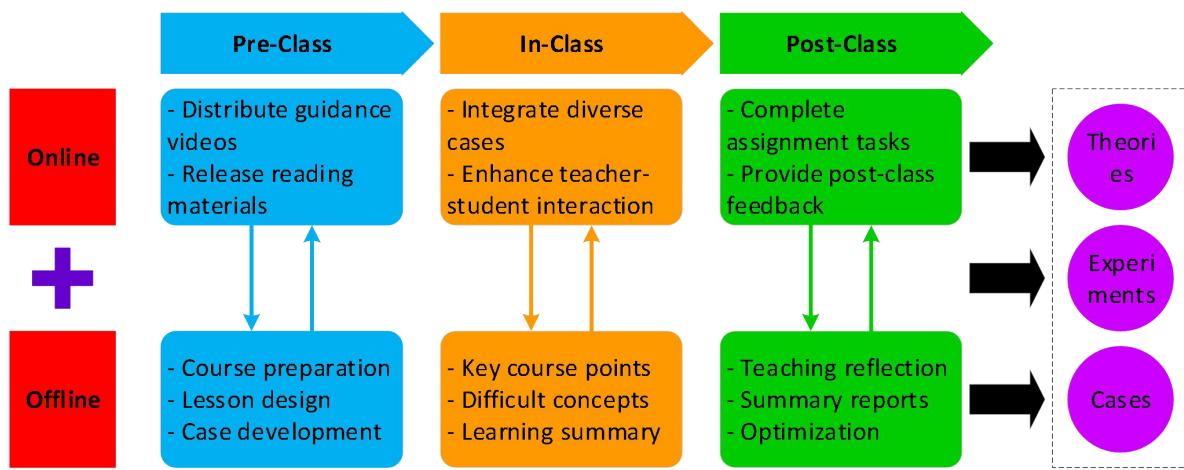
Figure 2 Blended Learning Model

In blended teaching design, problem-driven and project-based learning form the core of the design. Each instructional module is organized around a representative research question that serves as the central learning thread, accompanied by aligned exercises and project tasks. This structure enables students to achieve progressive development in cognition and research skills, from reproducing baseline models to conducting mini research projects aligned with their thesis topics. The online platform provides project guidelines, data resources, and demonstration code, whereas the offline classroom focuses on model specification, interpretation of results, and discussion of methodological limitations. Furthermore, instructors and teaching assistants offer tiered and differentiated guidance through staged project presentations, in-class feedback, and online Q&A sessions, which helps ensure the effective implementation of project-based learning.

In terms of AI empowerment, the course has undergone systematic exploration from both the instructor and student perspectives. Instructors use AI tools for assignment grading, summarizing common errors, generating multiple versions of exercises, and refining instructional explanations, thereby increasing the efficiency of teaching preparation and feedback. Students, under clearly defined guidelines, are permitted to use AI assistance for tasks such as literature translation and screening, code syntax checking, and figure and table refinement, thereby reducing their technical burdens and allowing greater effort to be devoted to problem formulation and empirical interpretation. To mitigate the risk of AI misuse, the course clearly distinguishes between "assistance" and "substitution" through thematic micro-lectures and in-class discussions. It emphasizes that AI must not replace independent thinking, fabricate data, or directly generate the main body of academic manuscripts, thereby reinforcing education on academic integrity.

Using the instructional unit "Panel Data Models and Stata Implementation" as an example, pre-class preparation employs guided videos and online quizzes to help students understand core concepts such as fixed effects and random effects. During in-class instruction, after a brief review of theoretical foundations, real-world data are used to demonstrate model specification, estimation procedures, and result evaluation, together with group discussions on model selection and interpretation of estimation outcomes. After class, students are assigned an analytical report based on a designated dataset. When addressing coding issues, students are allowed to use AI tools for preliminary debugging, with disclosure required upon submission; instructors then assess and provide feedback on the appropriateness and compliance of such use during grading. This approach effectively integrates knowledge acquisition, skill development, and the responsible use of analytical tools.

6 CONSTRUCTION OF A DIVERSIFIED AND INTELLIGENT LEARNING ASSESSMENT FRAMEWORK

To better leverage the role of assessment in guiding learning behaviors and promoting instructional improvement, our course establishes a comprehensive assessment system that includes formative assessment, summative assessment, and the evaluation of responsible AI use. In addition, learning analytics methods are introduced to further examine assessment outcomes and integrate the diagnostic, developmental, and feedback functions of assessment.

The formative assessment primarily consists of four categories of indicators. First, online learning behavioral data—including video completion rates, preparatory quiz performance, and participation in pop-up questions—are used to monitor students' learning engagement. Second, regular assignments and interim project outputs are used to evaluate students' understanding of theoretical knowledge and their ability to apply analytical methods in practice. Third, class participation—including offline oral presentations and interactions in online discussion forums—is assessed to reflect students' initiative and cognitive involvement in the learning process. Fourth, learning reflections and periodic summaries encourage students to conduct self-diagnosis, identify weaknesses, and formulate strategies for improvement. These indicators are incorporated into the overall course evaluation with assigned weights to encourage sustained learning engagement.

Summative assessment is primarily based on a course paper or research report, supplemented with a limited amount of comprehensive testing. The course paper requires students to carry out a complete data analysis workflow on either a self-selected or assigned topic. The evaluation criteria cover multiple dimensions, including problem identification,

methodological choice, software implementation, interpretation of results, and academic writing standards, thereby highlighting students' integrated competencies in authentic research contexts. The comprehensive assessments adopt open-ended question formats, deemphasizing rote memorization and emphasizing the understanding of statistical reasoning, model logic, and conditions of applicability, to assess students' overall mastery of the subject matter.

Given the widespread use of AI tools in the learning process, the course integrates standards for AI use into the assessment framework. Students are required to truthfully disclose the specific context and extent of AI tool use in major assignments and course papers. During the evaluation process, instructors issue warnings or request revisions for assignments that show excessive reliance on AI and insufficient evidence of independent understanding. Through a standardized mechanism encompassing ex ante notification, process monitoring, and ex post feedback, students are guided to develop an appropriate understanding of technology use and a strong awareness of academic integrity in practice.

Building on this foundation, the course further explores learning data generated through Rain Classroom to conduct learning analytics. For example, students are categorized on the basis of their online learning behavior patterns, and performance differences across assignments and course papers are compared across these groups. Correlations between variables such as video viewing completion rates, online quiz scores, and classroom participation and final course performance are examined to assess the appropriateness of assessment indicators and their assigned weights. The resulting analyses not only provide instructors with evidence to identify students at learning risk and implement targeted support but also offer data-driven guidance for adjusting course objective weightings, refining instructional strategies, and optimizing resource allocation in subsequent course iterations.

7 CONCLUSIONS

In this study, we take the postgraduate course *Statistical Analysis and Software Applications* as a case to systematically examine the implementation pathways for online open course development and blended teaching practices in the AI era. The findings indicate that reconstructing course objectives and content structures on the basis of a competency profile promotes the coordinated development of knowledge acquisition, skill development, and academic literacy. Using the Rain Classroom platform to develop a course website with a clear structure, rich resources, and explicit AI features provides strong support for the effective implementation of blended teaching. In the instructional process, a structured sequence of "online guidance-offline discussion-online extension" integrates problem-driven and project-based learning into teaching practices, significantly enhancing students' statistical thinking, software application skills, and research design capabilities. With respect to assessment design, a comprehensive evaluation framework integrating formative assessment, course papers, and standards for AI use—supplemented by learning analytics—provides actionable evidence for differentiated student support and a data-driven basis for continuous course optimization and iterative improvement.

Notably, this study is subject to limitations, including a relatively narrow sample scope and a comparatively short data period. Moreover, as AI technologies and instructional platforms continue to undergo rapid evolution, it is difficult for course design to fully stabilize in the short term. Future research may conduct comparative analyses across courses and institutions to further explore adaptive pathways for AI-enabled blended teaching across different disciplines and course types. In addition, the stability and scalability of the assessment indicator system and learning analytics models warrant examination across broader contexts. Overall, the course development experiences and practical pathways summarized in this study provide useful references for advancing online openness, blended reform, and the high-quality development of methods-oriented postgraduate courses.

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REFERENCES

[1] Tolentino R, Hersson-Edery F, Yaffe M, et al. AIFM-ed curriculum framework for postgraduate family medicine education on artificial intelligence: Mixed methods study. JMIR Medical Education, 2025, 11: e66828. https://doi.org/10.2196/66828.

[2] Parviz M, Lan G. A corpus-based investigation of phrasal complexity features and rhetorical functions in data commentary. Journal of Language and Education, 2023, 9(3): 90-109. https://doi.org/10.17323/jle.2023.16044.

[3] Wiredu JK, Abuba NS, Zakaria H. Impact of generative AI in academic integrity and learning outcomes: A case study in the upper east region. Asian Journal of Research in Computer Science, 2024, 17(8): 70-88. https://doi.org/10.9734/ajrcos/2024/v17i7491.

[4] Pacifico JL, van Mook W, Donkers J, et al. Extending the use of the conceptions of learning and teaching (COLT) instrument to the postgraduate setting. BMC Medical Education, 2021, 21(1). https://doi.org/10.1186/s12909-020-02461-2.

[5] Altmiller G, et al. Curriculum mapping for competency-based education: Collecting objective data. Nurse Educator, 2023, 48(5): 287. https://doi.org/10.1097/NNE.000000000001462.

[6] Akhtar MH, Anderson M, Cochrane T. Implementing augmented reality and virtual reality for authentic healthcare education: Technology-enhanced healthcare education for low-resource settings with a focus on Australasia. Pacific Journal of Technology Enhanced Learning, 2024, 6(1): 2-3. https://doi.org/10.24135/pjtel.v6i1.177.

[7] Hu SB, Fang YH, Bai Y. Automation and optimization in crane lift planning: A critical review. Advanced Engineering Informatics, 2021, 49: 101346. https://doi.org/10.1016/j.aei.2021.101346.

[8] Iyamuremye A, Twagilimana I, Niyonzima FN. 8Bs instructional model for knowledge construction using web-based discussion tools. Discover Education, 2025, 4(1): 185. https://doi.org/10.1007/s44217-025-00614-3.

[9] Ruano-Borbalan JC. Understanding and fostering the development of critical thinking education and competences. European Journal of Education, 2023, 58(3): 347-353. https://doi.org/10.1111/ejed.12572.

[10] Liu FQ, Qu SM, Fan Y, et al. Scientific creativity and innovation ability and its determinants among medical postgraduate students in Fujian Province of China: A cross-sectional study. BMC Medical Education, 2023, 23(1). https://doi.org/10.1186/s12909-023-04408-9.

[11] Li XY, Meng FQ. Research on the reform and practice of statistics teaching under the ideological and political concept of curriculum. Advances in Education, 2023, 13(5): 2329-2334. https://doi.org/10.12677/AE.2023.135366.

[12] Alenezi M, Wardat S, Akour M. The need of integrating digital education in higher education: Challenges and opportunities. Sustainability, 2023, 15(6): 4782. https://doi.org/10.3390/su15064782.

[13] Huang R. Teaching quality evaluation of online courses based on AHP-FCE evaluation technology. International Journal of Emerging Technologies in Learning (iJET), 2023, 18(13): 91-103. https://doi.org/10.3991/ijet.v18i13.40391.

[14] Wang RM, Ling HL, Chen J, et al. An integrated LDA-QFD approach for improving online course quality based on learners' reviews. International Journal of Distance Education Technologies, 2025, 23(1). https://doi.org/10.4018/IJDET.371203.

[15] Southworth J, Migliaccio K, Glover J, et al. Developing a model for AI across the curriculum: Transforming the higher education landscape via innovation in AI literacy. Computers and Education: Artificial Intelligence, 2023, 4: 100127. https://doi.org/10.1016/j.caeai.2023.100127.

[16] Jia XY, Pang Y, Liu LS. Online health information seeking behavior: A systematic review. Healthcare, 2021, 9(12): 1740. https://doi.org/10.3390/healthcare9121740.

[17] Ma G. The blended model of online and offline instruction of "five links and two stages": A case study of outline of Chinese modern and contemporary history. Journal of Higher Education Teaching, 2024, 1(4): 177-182. https://doi.org/10.62517/jhet.202415427.

[18] Palanci A, Yılmaz RM, Turan Z. Learning analytics in distance education: A systematic review study. Education and Information Technologies, 2024, 29(17): 22629-22650. https://doi.org/10.1007/s10639-024-12737-5.

[19] Lv H, Low JH, Tan SK, et al. Factors affecting medical students' intention to use Rain Classroom: A cross-sectional survey. BMC Medical Education, 2024, 24(1): 86. https://doi.org/10.1186/s12909-024-05037-6.

[20] Lapitan LDS, Tiangco CE, Sumalinog DAG, et al. An effective blended online teaching and learning strategy during the COVID-19 pandemic. Education for Chemical Engineers, 2021, 35: 116-131. https://doi.org/10.1016/j.ece.2021.01.012.

[21] Chen J. Effectiveness of blended learning to develop learner autonomy in a Chinese university translation course. Education and Information Technologies, 2022, 27(9): 12337-12361. https://doi.org/10.1007/s10639-022-11125-1.

[22] Jiandani MP. Enhancing faculty development: A vital need. Physiotherapy - The Journal of Indian Association of Physiotherapists, 2023, 17(2). https://doi.org/10.4103/pjiap.pjiap_42_23.

[23] Li MQ, Wang X, Du YL, et al. Based on digital intelligence: Teaching innovation and practice of veterinary internal medicine in China's southwest frontier. Frontiers in Veterinary Science, 2025, 12. https://doi.org/10.3389/fvets.2025.1651179.

[24] Ruiz JG, Torres JM, Crespo RG. The application of artificial intelligence in project management research: A review. International Journal of Interactive Multimedia and Artificial Intelligence, 2021, 6(6): 54-66. https://doi.org/10.9781/ijimai.2020.12.003.

[25] Ariely M, Nazaretsky T, Alexandron G. Causal-mechanical explanations in biology: Applying automated assessment for personalized learning in the science classroom. Journal of Research in Science Teaching, 2024, 61(8): 1858-1889. https://doi.org/10.1002/tea.21929.

[26] Bridgelall R. Unraveling the mysteries of AI chatbots. Artificial Intelligence Review, 2024, 57(4): 89. https://doi.org/10.1007/s10462-024-10720-7.

[27] Rahman MT, Terano HJR, Rahman N, et al. ChatGPT and academic research: A review and recommendations based on practical examples. Journal of Education, Management and Development Studies, 2023, 3(1): 1-12. https://doi.org/10.52631/jemds.v3i1.175.

[28] Karim NA, Isa CMM, Noor SMA. A methodological framework for AI-integrated alternative assessments in engineering education. Jurnal Kejuruteraan, 2025, 37(2): 807-819. https://doi.org/10.17576/jkukm-2025-37(2)-20.

[29] Dalisaymo L. Assessing student dependence on artificial intelligence tools. The International Journal of Technologies in Learning, 2025, 32(2): 67-81. https://doi.org/10.18848/2327-0144/cgp/v32i02/67-81.

[30] Fan YZ, Tang LZ, Le HX, et al. Beware of metacognitive laziness: Effects of generative artificial intelligence on learning motivation, processes, and performance. British Journal of Educational Technology, 2025, 56(2): 489-530. https://doi.org/10.1111/bjet.13544.

[31] Flanagin A, Bibbins-Domingo K, Berkwits M, et al. Nonhuman "authors" and implications for the integrity of scientific publication and medical knowledge. JAMA, 2023, 329(8): 637-639. https://doi.org/10.1001/jama.2023.1344.

PLACE BASED AND CULTURALLY RESPONSIVE REFORM OF AN INTRODUCTION TO ENVIRONMENTAL SCIENCE COURSE IN QINGHAI ON THE QINGHAI TIBETAN PLATEAU: CURRICULUM DESIGN AND AN OUTCOMES EVALUATION FRAMEWORK

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Abstract: Qinghai Province lies in western China on the northeastern margin of the Qinghai Tibetan Plateau and is widely recognized for both ecological vulnerability and cultural diversity. Local environmental issues such as watershed security in headwater regions, grassland degradation, solid waste pressures linked to urbanization and tourism, and climate related hazards are not only biophysical problems but also questions of livelihoods, cultural practice, and governance. In many universities serving this region, the Introduction to Environmental Science course remains organized around generic textbook chapters and lecture centered delivery. Such arrangements often fragment students' understanding of ecological systems and provide limited opportunities to practice evidence based inquiry, reasoning about trade offs, or communicating across cultural and linguistic differences. Drawing on place based education and the critical pedagogy of place, and on culturally relevant, culturally responsive, and culturally sustaining perspectives, this paper develops a localized curriculum reform for the course and a coherent outcomes evaluation framework aligned with Education for Sustainable Development. The reform integrates local issue driven project units with core disciplinary concepts, adopts project based learning and authentic assessment as the primary instructional approach, and embeds participation supports intended to reduce inequities in multiethnic classrooms. The evaluation framework specifies measurable learning outcomes across conceptual understanding, environmental attitudes and literacy, systems thinking, evidence based decision making, and intercultural collaboration, and it proposes a mixed methods analytic strategy combining pre and post measures, rubric scored artifacts, classroom analytics, and qualitative analyses of interviews and learning journals. As a design based study, the paper reports the resulting curriculum architecture, task sets, and scoring tools as concrete products that can be adapted by universities in other multiethnic and environmentally sensitive regions.
Keywords: Environmental science education; Place based education; Culturally responsive teaching; Multiethnic higher education; Qinghai Tibetan Plateau; Project based learning; Authentic assessment; Environmental literacy; Education for Sustainable Development

1 INTRODUCTION

1.1 Background and Problem Statement

Qinghai Province is located in western China and forms part of the Qinghai Tibetan Plateau, a region often described as ecologically fragile and sensitive to external disturbances [1,2]. Qinghai is also a multiethnic province in which ethnic minority populations constitute a substantial share of residents [3]. These features are not simply contextual details; they shape what environmental problems look like, whose interests are affected, and how solutions are negotiated. For example, discussions about water security and watershed management in headwater regions are inseparable from questions of upstream downstream equity, land use regimes, and community participation, and contemporary research continues to refine widely held assumptions about the plateau's contribution to runoff and downstream water supply [4]. Similarly, issues such as pasture degradation, biodiversity protection, and waste management often sit at the intersection of ecological processes, economic development priorities, and cultural traditions. Yet, in many higher education settings, the Introduction to Environmental Science course is still organized as a survey of concepts and pollutant categories delivered through lectures and decontextualized examples. Students may memorize terms without learning how to frame problems, evaluate evidence, or communicate with stakeholders, and this limitation becomes more visible in multiethnic classrooms where language practices and communicative norms vary. In such settings, the course can inadvertently reproduce inequities by privileging students whose academic discourse aligns most closely with dominant classroom styles while marginalizing the knowledge resources and lived experiences of others.

1.2 Purpose and Research Questions

Responding to these challenges, the present study develops a place based and culturally responsive reform of the Introduction to Environmental Science course, using Qinghai as a case of a plateau region where environmental issues are tightly coupled with cultural diversity. The immediate goal is practical: to propose a course structure that links local issues to core disciplinary concepts, supports student inquiry through project based learning, and assesses learning through authentic tasks and transparent rubrics. The broader goal is scholarly: to articulate design principles and an outcomes evaluation framework that can inform environmental and sustainability education in other multiethnic regions. The paper addresses three questions. First, how can course content be reconstructed around local issues so that conceptual learning is continuously connected to evidence and decision contexts, rather than presented as an isolated body of knowledge. Second, how can culturally relevant and sustaining supports be embedded in everyday teaching routines to promote equitable participation, collaborative communication, and professional identity development among students from different ethnic and linguistic backgrounds. Third, how can an assessment system be designed so that learning outcomes such as environmental literacy, systems thinking, and evidence based reasoning are evaluated with validity and transparency, using a mixed methods approach suited to complex educational interventions [5].

2 LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1 Place based Education and the Critical Pedagogy of Place

Place based education has been advanced as a way to ground learning in the local community and natural environment so that knowledge becomes intelligible through the conditions of everyday life rather than as an abstract body of facts. Within environmental education, this tradition typically foregrounds experiential learning, attention to local ecological processes, and civic engagement. However, critiques of purely celebratory place based approaches have noted that places are also sites of contestation, where historical trajectories, governance arrangements, and uneven power relations shape access to resources and exposure to environmental risks. Gruenewald argued that critical pedagogy and place based education can be brought into productive dialogue through a critical pedagogy of place that asks educators to consider both reinhabitation, meaning the development of sustainable relationships with local ecosystems, and decolonization, meaning the interrogation of social and cultural structures that marginalize some communities [6]. Greenwood further emphasized that environmental education benefits from acknowledging difference and standpoint, because multiple perspectives can expand inquiry rather than producing gridlock [7]. For environmental science teaching in Qinghai, these arguments imply that local cases should be treated as more than illustrative examples; they should become the organizing backbone of the curriculum, prompting students to analyze how ecological vulnerability, livelihood strategies, and governance choices interact at different spatial and temporal scales. In this sense, place is a bridge between scientific concepts and ethical decision making, and a critical place perspective can help students learn to work with evidence while also recognizing that environmental problems are lived and negotiated by communities.

2.2 Culturally Relevant, Culturally Responsive, and Culturally Sustaining Pedagogy

Environmental issues in multiethnic regions are always interpreted through cultural frames, and students' willingness to engage in environmental learning often depends on whether their histories and lived experiences are treated as legitimate forms of knowledge. Ladson Billings described culturally relevant pedagogy as a framework that integrates academic achievement, cultural competence, and critical consciousness, rejecting deficit views of students from nondominant groups and instead positioning culture as a resource for learning [8]. Gay elaborated culturally responsive teaching as the deliberate use of students' cultural knowledge and communicative practices to make instruction more effective, which has implications for curriculum materials, discourse norms, and assessment [9]. Paris extended this line of work by advocating culturally sustaining pedagogy, emphasizing that schooling should sustain linguistic and cultural pluralism rather than assimilating students into a single dominant norm [10]. In Qinghai higher education, culturally responsive approaches can address two practical needs at once: the need to broaden participation and the need to enrich environmental reasoning with diverse forms of place knowledge. Concretely, these approaches suggest the value of multimodal resources, opportunities for students to draw on local languages and community knowledge in sense making, and group work structures that distribute voice and responsibility. They also suggest that equity is not an add on but a design criterion, because who speaks and whose evidence is regarded as credible shapes how students learn to think about environmental governance and sustainability.

2.3 Project based Learning and Authentic Assessment

Project based learning is widely defined as an instructional approach in which students engage over an extended period with complex questions or problems that culminate in a publicly shareable product. In their review, Kokotsaki, Menzies, and Wiggins showed that PBL is most likely to produce positive learning outcomes when projects are structured around meaningful driving questions, when teachers provide timely scaffolding, and when assessment practices are aligned with intended outcomes [11]. These findings are particularly relevant for introductory environmental science because students must integrate multiple knowledge sources, handle uncertainty, and communicate to audiences beyond the classroom. Authentic assessment offers a complementary rationale for evaluation. Wiggins argued that assessment becomes authentic when it directly examines performance on intellectually worthy tasks rather than relying on proxy items that may reward rote recall [12]. Gulikers, Bastiaens, and Kirschner proposed a multidimensional framework for

authenticity that includes the task itself, its physical and social context, the nature of the assessment product, and the criteria used to judge it [13]. Taken together, these perspectives suggest that assessment in a reformed Introduction to Environmental Science course should prioritize evidence rich products such as policy memos, monitoring plans, or risk communication artifacts, accompanied by transparent rubrics that represent disciplinary standards while leaving room for local and cultural specificity. In this paper, PBL is adopted as the primary instructional engine, and authentic assessment is treated as the quality control mechanism that keeps learning activities, outcomes, and evaluation in alignment.

2.4 Environmental Literacy and Education for Sustainable Development

Environmental literacy has been conceptualized as a composite of knowledge, dispositions, and competencies that enable individuals to identify environmental issues, analyze causes, evaluate solutions, and take informed action. The Revised New Ecological Paradigm scale developed by Dunlap, Van Liere, Mertig, and Jones remains among the most widely used instruments for measuring pro environmental worldviews, and it provides a useful component for evaluating attitudinal change in higher education settings [14]. For broader competency mapping, Hollweg and colleagues proposed an environmental literacy assessment framework that differentiates knowledge of ecological and socio political systems, competencies for issue analysis and decision making, and dispositions toward the environment [15]. At the policy level, UNESCO's Education for Sustainable Development roadmap emphasizes that education should equip learners with knowledge, skills, values, and behaviors that support the environment, the economy, and society, while also strengthening education systems and learning environments [16]. For a course situated in Qinghai, an environmental literacy lens prevents evaluation from collapsing into content recall alone, while an ESD lens helps link local issues to broader sustainability goals, including equity and participation. In this study, environmental literacy and ESD jointly inform the outcomes framework, the selection of tasks, and the design of instruments for capturing learning in ways that are meaningful both locally and internationally.

3 METHODS

3.1 Research Design and Overall Approach

The study is framed as design based research, an approach that blends theory driven design with empirical inquiry in authentic settings and seeks to generate both practical improvements and transferable knowledge about why an innovation works [17,18]. In the context of a university course, design based research is compatible with participatory action research, which emphasizes iterative cycles of planning, acting, observing, and reflecting with practitioners and learners as co participants [19]. The reform reported here therefore treats curriculum development as a cycle of design decisions that are continuously tested against the realities of a multiethnic classroom. The paper documents the resulting curriculum architecture and provides an outcomes evaluation framework that can be used to study learning impacts through mixed methods. In line with mixed methods logic, the evaluation plan integrates quantitative measures (knowledge, attitudes, rubric scores) with qualitative evidence (interviews, journals, observation notes, artifact analysis) to support both outcome claims and explanatory insights about mechanisms [5].

3.2 Context, Course Setting, and Participants

The reform is designed for the compulsory Introduction to Environmental Science course offered in universities in Qinghai. The course typically enrolls first and second year undergraduates from different majors, including environmental science related programs and general education tracks, and it includes students from Han and multiple ethnic minority groups. While the present paper does not rely on a single institution's administrative data for its claims, the design assumptions are grounded in widely observed conditions in the region: students bring diverse language repertoires, some have direct experience with pastoral or agricultural livelihoods, and many are motivated by regional issues such as water security, nature reserve governance, and green development. The intervention therefore treats linguistic diversity and varied place experiences as design inputs rather than implementation constraints, and it seeks to provide multiple entry points for participation in inquiry and assessment.

3.3 Intervention Description: Curriculum Architecture and Instructional Routines

The reformed course is organized as a sequence of local issue driven project units. Each unit is built around a driving question that cannot be answered through recall alone, requires the use of evidence, and forces students to reason about trade offs. Core disciplinary concepts are introduced through short targeted lectures and guided readings, then applied through sustained inquiry and product development. Instruction follows a six phase routine: an entry event that introduces a local issue through data or media, refinement of a driving question and success criteria, evidence gathering and analysis supported by methodological mini lessons, iterative solution development with checkpoints, public presentation to an authentic audience, and structured reflection that feeds into subsequent units. Throughout the course, culturally responsive participation supports are embedded in group formation, language scaffolds, and multimodal communication options. Assessment is anchored in authentic products and transparent rubrics, with formative feedback provided at multiple stages so that evaluation functions as part of learning rather than as a terminal judgment [12,13].

3.4 Data Sources and Instruments for Outcomes Evaluation

The evaluation framework proposes four complementary streams of evidence. First, conceptual learning and systems understanding can be assessed through scenario based tests administered pre and post, combining multiple choice items that capture key concepts (e.g., watershed processes, pollution pathways, ecological carrying capacity) with constructed response tasks requiring causal explanations and solution justification. Second, dispositions and attitudes can be examined using validated scales, including the Revised New Ecological Paradigm scale as a measure of ecological worldview, alongside a tailored environmental literacy questionnaire informed by the NAAEE framework [14,15]. Third, performance outcomes are captured through rubric scored project artifacts, including policy memos, monitoring plans, stakeholder maps, and risk communication products. The analytic rubric includes dimensions for evidence quality, systems reasoning, solution feasibility, equity and cultural responsiveness, and communication effectiveness. Fourth, process and mechanism evidence is collected through structured classroom observations, student learning journals, focus group interviews, and reflective interviews with instructors. Together, these sources support triangulation: quantitative shifts can be interpreted in light of qualitative accounts of participation, sense making, and identity.

3.5 Quantitative and Qualitative Analysis Framework

Quantitative analyses focus on estimating the magnitude and uncertainty of learning changes. Pre post comparisons for knowledge scores and scale measures can be examined using paired samples t tests when distributional assumptions are met, or Wilcoxon signed rank tests as a robust alternative. When multiple sections or demographic groups are compared, ANCOVA models can be used to adjust post scores for pre scores, and interaction terms can explore whether the intervention is associated with differential gains. Effect sizes (Cohen's d or r) and confidence intervals should be reported to avoid over reliance on p values. Scale reliability should be assessed with internal consistency indices such as Cronbach's alpha, and, when sample size permits, factorial validity can be explored using exploratory or confirmatory factor analysis to check whether the adapted instruments retain expected structure. For rubric scored artifacts, inter rater reliability should be estimated using intraclass correlation coefficients and rater calibration sessions should be documented. Qualitative analyses are structured around thematic analysis. Observation notes, interviews, and learning journals can be coded inductively and deductively, with a codebook that includes categories aligned to the conceptual framework (e.g., evidence use, systems connections, cultural references, equity concerns, collaboration dynamics) while leaving room for emergent themes. Credibility can be strengthened through double coding of a subset of data, discussion of discrepancies, and member checking with participants where feasible. Mixed methods integration occurs through joint displays that align numeric trends with qualitative explanations, for example by linking shifts in environmental worldview scores to narrative accounts of how students negotiated value conflicts in projects [5].

3.6 Ethical Considerations and Quality Assurance

Ethical practice is central when curriculum work involves community issues and cultural knowledge. Data collection should be conducted with informed consent, clear options to opt out of research participation without academic penalty, and careful protection of student identity in publications. When community stakeholders are involved as authentic audiences, their role should be negotiated to avoid extractive use of local knowledge, and student outputs should not be represented as official policy advice. Quality assurance includes transparent documentation of design decisions, maintenance of an audit trail linking data to interpretations, and explicit reporting of limitations such as nonrandom assignment or small sample sizes in single course settings. These measures align the study with best practices for rigorous educational design research, see Table 1.

Table 1 Outcomes, Evidence Sources, and Analysis Plan

Outcome domain	Evidence source	Representative indicators	Primary analysis
Conceptual understanding and transfer	Scenario based pre/post test; short constructed responses	Accurate causal explanation; correct use of core concepts; transfer to Qinghai cases	Paired t test or Wilcoxon; effect size; item analysis
Environmental attitudes and dispositions	Revised NEP; environmental literacy questionnaire	Change in ecological worldview; perceived responsibility; willingness to act	Reliability (α); pre/post comparison; subgroup analysis when appropriate
Systems thinking and evidence based decision making	Project artifacts scored with analytic rubric	Quality of evidence; explicit trade off reasoning; multi scale system map; solution feasibility	Rubric score distributions; ICC for rater reliability; correlations with test scores
Intercultural collaboration and participation equity	Observation protocol; peer assessment; group process logs; interviews	Turn taking balance; role rotation; conflict resolution; inclusion of local knowledge	Thematic analysis; joint displays linking themes to performance trends

4 RESULTS

4.1 The Localized Curriculum Structure

The first product of the design work is a curriculum architecture that interleaves local environmental issues with core concepts in environmental science. Instead of sequencing the course by pollutant type or disciplinary subfield, the course is organized by regional problems that naturally require students to draw on hydrology, ecology, atmospheric science, geochemistry, and environmental policy. Each unit follows a consistent pattern: students begin with a locally recognizable situation, identify what counts as credible evidence, map the socio ecological system and stakeholders, and then design and communicate a feasible response. This structure reduces fragmentation by repeatedly returning students to a small set of recurring intellectual moves: issue framing, causal reasoning, system mapping across scales, evaluation of alternative solutions, and communication to audiences. Across units, conceptual goals spiral rather than accumulate linearly, so that foundational ideas such as carrying capacity, feedback, threshold effects, and risk trade offs are revisited in new contexts. The design therefore treats core content as a set of tools for reasoning about place, aligning with a critical pedagogy of place that links reinhabitation and decolonization to disciplinary learning [6,7].

4.2 Project Units and Driving Questions.

Five exemplar units were developed to cover the breadth of introductory environmental science while staying anchored in Qinghai's plateau context. The first unit, Watersheds and headwater security, uses the region's role as a source area for major rivers to examine watershed processes, water quality indicators, and governance tensions between conservation and development, drawing attention to contemporary scientific debates about runoff contributions and water tower narratives [4]. A typical driving question asks: What combination of monitoring, demand management, and policy coordination would most effectively protect downstream water quality while respecting local livelihood needs. The second unit, Grasslands, soils, and livelihood change, examines land degradation, soil erosion, and the ecological consequences of grazing intensity, with students modeling causal pathways and exploring how ecological vulnerability varies across the plateau [2]. The third unit, Urbanization, tourism, and solid waste, addresses waste classification, life cycle thinking, and the infrastructure challenges of managing waste streams in cold, high altitude environments. The fourth unit, Biodiversity and protected areas, centers on ecological networks, habitat fragmentation, and the governance of protected areas, including the role of community co management. The fifth unit, Climate change and disaster risk, connects regional warming trends to glacier and snow dynamics, extreme weather events, and adaptation strategies. Each unit culminates in a product designed for a plausible audience such as a park management committee, a county environmental bureau, a community association, or a campus sustainability office. This audience orientation is not decorative; it forces students to translate scientific language into actionable recommendations and to anticipate counterarguments rooted in values and constraints.

4.3 Task Design and Instructional Scaffolds

To make extended inquiry feasible in an introductory course, each project is decomposed into a sequence of checkpoints that progressively build disciplinary competence. Early checkpoints require students to construct a shared evidence base, often by working with a curated packet that includes short research articles, statistical tables, monitoring datasets, and policy excerpts. Subsequent checkpoints prompt students to create system representations such as causal loop diagrams, stakeholder influence maps, and simple mass balance or water budget models. Mini lessons are then offered responsively to address methodological needs that emerge from student work, for example how to interpret remote sensing images, how to distinguish correlation from causation in environmental data, or how to evaluate uncertainty and data limitations. Teachers also provide language scaffolds that support academic discourse, including structured sentence frames for claims and evidence, bilingual glossaries for key terms, and templates for executive summaries. These supports are designed so that academic rigor is not lowered but access is widened, consistent with culturally responsive teaching principles [9]. Importantly, students are required to revise products after feedback, which shifts assessment from one time performance to a process of improvement and makes rubric criteria consequential for learning.

4.4 Embedding Culturally Responsive Participation Supports

The reform specifies participation routines intended to reduce inequities that can appear in multiethnic classrooms. Group formation is intentional and dynamic: teams are constructed to include different majors and backgrounds, and roles rotate across projects so that the same students do not repeatedly become translators, note takers, or presenters. Role expectations are made visible through short behavioral descriptors so that peer evaluation can focus on observable contributions rather than vague impressions. To support linguistic pluralism while maintaining academic standards, the course allows students to use local languages in early sense making discussions, especially when eliciting place knowledge and community perspectives, while final products require a common academic language and a short bilingual abstract where feasible. Multimodal options are also built into products: students may combine maps, infographics, short videos, and narrative accounts alongside formal scientific writing. These design choices respond to the core idea of culturally sustaining pedagogy that education should sustain cultural and linguistic resources rather than treating them as barriers [10]. In the Qinghai context, where some students have direct experience with pastoral landscapes and others have urban backgrounds, these supports also broaden what counts as relevant experience in environmental reasoning, without substituting experience for evidence.

4.5 The Authentic Assessment System and Rubric Structure

The second major product is an assessment system that aligns with project based learning and environmental literacy outcomes. Following the rationale of authentic assessment and multidimensional authenticity, the system uses two categories of evidence: performance products and learning reflections [12,13]. Performance products include a main deliverable for each unit and supporting artifacts such as system maps, annotated bibliographies, and data analysis worksheets. Learning reflections include short individual memos in which students explain how their thinking changed, what evidence shifted their view, and how they navigated value conflicts in group work. The analytic rubric is the main scoring tool. Rather than collapsing quality into a single score, the rubric makes disciplinary standards explicit through dimensions for evidence quality, systems reasoning, feasibility of recommendations, attention to equity and cultural context, and communication for the intended audience. The rubric is designed for formative use: drafts are scored at checkpoints, students receive narrative feedback linked to criteria, and revisions are expected. This makes the assessment system both more transparent and more instructionally useful, and it provides richer data for evaluation than a final exam alone, see Table 2.

Table 2 Excerpt from the Analytic Rubric for Project Products

Dimension	Beginning	Developing	Proficient	Advanced
Use of evidence	Claims are largely unsupported; sources are missing or not credible.	Uses some sources but evidence is selectively interpreted or weakly linked to claims.	Uses multiple credible sources; explains how evidence supports claims; notes limitations.	Synthesizes diverse evidence (data, literature, policy); evaluates uncertainty and alternative explanations.
Systems reasoning	Lists factors without explaining relationships or feedback.	Identifies some causal links but system boundaries and scale are unclear.	Explains causal pathways and interactions across ecological and social components; considers scale.	Models feedback, thresholds, and trade offs; articulates how interventions may shift system behavior over time.
Feasibility and ethics	Recommendations are vague, unrealistic, or ignore constraints and affected groups.	Recommendations address the issue but feasibility, costs, or equity are only partly considered.	Recommendations are feasible in the local context; considers constraints, trade offs, and equity impacts.	Recommendations integrate technical, economic, cultural, and governance considerations; anticipates objections and proposes mitigation.
Communication for audience	Message is unclear; structure and visuals hinder understanding.	Basic structure is present but key messages or visuals are inconsistent.	Clear, well structured communication; visuals support interpretation; appropriate tone for audience.	Compelling narrative with concise executive summary; strong visual communication; adapts language for diverse audiences.

4.6 The Mixed Methods Outcomes Evaluation Framework

The evaluation framework operationalizes environmental literacy and ESD aligned outcomes into indicators that can be measured without reducing the complexity of learning. The knowledge component distinguishes between ecological system understanding and knowledge of socio political systems, consistent with environmental literacy frameworks [15]. Competency indicators focus on the ability to identify and frame issues, analyze evidence, evaluate solutions, and justify actions, while disposition indicators include ecological worldview and perceived efficacy. Importantly, the framework also treats intercultural collaboration as an outcome rather than a mere process variable, because in multiethnic contexts collaboration is a competency with real social consequences. In reporting, the framework encourages the use of joint displays that show how quantitative shifts align with qualitative themes. For example, a joint display might juxtapose changes in students' NEP scores with excerpts from reflection memos where students describe how their beliefs were challenged by evidence about trade offs between conservation and local livelihoods. Similarly, rubric score trajectories on the systems reasoning dimension can be interpreted alongside observation notes about group dialogue patterns, such as whether students explicitly connected upstream land use to downstream water quality or whether system maps remained linear and simplistic. These forms of integration align with mixed methods design logic and are particularly suited to design based research where understanding mechanisms matters as much as documenting outcomes [5,17].

4.7 Reporting Templates for Quantitative and Qualitative Results

To support replicable reporting, the framework includes a set of reporting conventions that can be adopted when empirical data are collected. Quantitative reporting should begin with descriptive statistics (means, standard deviations, score distributions) and reliability indices for all scales and rubrics, followed by pre post comparisons with effect sizes and confidence intervals. Where subgroup comparisons are relevant, demographic variables should be reported descriptively and interpreted cautiously, with attention to the fact that linguistic and cultural identities do not map neatly onto performance patterns. Qualitative reporting should include a transparent description of data volume, coding

procedures, and representative excerpts for major themes. Themes are most persuasive when they are linked to concrete episodes of project work, such as moments when groups negotiated which evidence sources were credible or how to frame an audience facing competing pressures. Finally, mixed methods integration should be explicit rather than implied: tables or narrative joint displays should state what qualitative themes explain or complicate quantitative patterns and what unresolved tensions remain. These templates are included because they reduce the risk that future empirical studies of the reform will rely on generic claims; they also make it easier for instructors to treat evaluation as part of iterative improvement.

5 DISCUSSION

5.1 Contributions to Environmental Science Education in Multiethnic Contexts

The central contribution of this paper is to show how an introductory environmental science course can be redesigned so that place, culture, and evidence become mutually reinforcing rather than competing priorities. The curriculum architecture treats local issues as organizing problems that repeatedly require students to use disciplinary concepts for explanation and action, which addresses a common weakness of survey courses where concepts remain disconnected from decision contexts. At the same time, culturally responsive and sustaining supports are embedded in routine teaching practices, not reserved for special topics. This matters because multiethnic classrooms often face a double risk: inequities in participation can mirror broader social hierarchies, and environmental topics can become politically or culturally sensitive when they touch on land use, livelihood change, or governance. By making participation structures explicit and by valuing local knowledge while insisting on evidence based justification, the design aims to cultivate a professional identity in which students learn to see themselves as credible contributors to regional sustainability work. From a theoretical standpoint, the design operationalizes the critical pedagogy of place by treating reinhabitation as a scientific learning goal and decolonization as an equity and participation goal, thereby making the concept actionable in course design [6,7].

5.2 Implications for Assessment and Evaluation

A second contribution lies in the outcomes evaluation framework. Environmental science education reforms often struggle to evaluate outcomes that go beyond content recall. The framework presented here makes those outcomes measurable by linking them to observable products and behaviors. By combining validated attitude measures such as the Revised NEP with performance based rubrics aligned to environmental literacy competencies, the framework balances psychometric traditions with authentic assessment traditions [14,15]. This balance is important because the skills demanded by ESD, such as reasoning about trade offs and acting under uncertainty, are difficult to capture through conventional exams [16]. The mixed methods design further acknowledges that numbers alone rarely explain why learning changes, especially when interventions include changes in classroom culture, participation norms, and identity. The proposed integration strategy, using joint displays and mechanism oriented qualitative analyses, provides a practical way to report outcomes without oversimplifying them [5].

5.3 Limitations and Directions for Future Research

Because this paper is primarily a design report, it does not present large scale empirical outcome estimates. The next step is systematic implementation and evaluation across cohorts and institutions, with careful documentation of fidelity and local adaptation. Future studies should also examine how language supports interact with disciplinary rigor, for example whether bilingual scaffolds help students articulate more precise causal explanations or whether they primarily affect participation patterns. Another promising direction is to investigate how different types of authentic audiences influence student motivation and quality of reasoning, since stakeholder presence can both motivate and constrain what students are willing to argue. Finally, researchers should treat cultural responsiveness as an empirical question as well as a normative commitment by examining whether participation equity and learning gains are distributed more evenly across student groups under the redesigned course. Such work will strengthen the evidence base for place based environmental science education in culturally diverse regions and will contribute to international conversations about sustainability education that is both locally grounded and globally informed.

6 CONCLUSION

This paper developed a place based and culturally responsive reform for an Introduction to Environmental Science course situated in Qinghai on the Qinghai Tibetan Plateau. The reform responds to the intertwined ecological and cultural characteristics of the region by reorganizing content around local issue driven projects, embedding culturally sustaining participation supports, and adopting authentic assessment as the main evaluation approach. The paper also specified an outcomes evaluation framework that aligns environmental literacy with Education for Sustainable Development goals and that offers a mixed methods analytic strategy capable of capturing both learning outcomes and the mechanisms that produce them. Although future empirical studies are needed to estimate impact, the curriculum architecture, task sets, and rubrics reported here provide a concrete pathway for universities seeking to localize

introductory environmental science teaching in multiethnic contexts while maintaining rigorous evidence based reasoning and transparent assessment.

COMPETING INTERESTS

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

REFERENCES

[1] Qinghai Provincial People's Government. Overview of Qinghai (Geography and administrative division). 2016. Available from: https://www.qinghai.gov.cn/dmqh/glp/

[2] Xia M, Jia K, Zhao W, et al. Spatio-temporal changes of ecological vulnerability across the Qinghai-Tibetan Plateau. Ecological Indicators, 2021, 123, 107274. DOI: 10.1016/j.ecolind.2020.107274.

[3] Qinghai Provincial Bureau of Statistics. Qinghai statistical yearbook 2023: Table 3-4 Population of ethnic minorities (2006–2022). 2023. Available from: https://tjj.qinghai.gov.cn/nj/2023/html/0304.htm

[4] Tian F, Nan Z, Zhang Y, et al. Is the Tibetan Plateau really a water tower? Hydrological Processes, 2024, 38, e15103. DOI: 10.1002/hyp.15103.

[5] Creswell J W, Plano Clark V L. Designing and conducting mixed methods research (3rd ed.). SAGE. 2018. Available from: https://collegepublishing.sagepub.com/products/designing-and-conducting-mixed-methods-research-3-241842

[6] Gruenewald DA. The best of both worlds: A critical pedagogy of place. Educational Researcher, 2003, 32(4): 3-12. DOI: 10.3102/0013189X032004003.

[7] Greenwood DA. A critical pedagogy of place: From gridlock to parallax. Environmental Education Research, 2008, 14(3): 336-348. DOI: 10.1080/13504620802190743.

[8] Ladson-Billings G. Toward a theory of culturally relevant pedagogy. American Educational Research Journal, 1995, 32(3): 465-491. DOI: 10.3102/00028312032003465.

[9] Gay G. Culturally responsive teaching: Theory, research, and practice. Teachers College Press, 2000. Available from: https://www.tcpress.com/culturally-responsive-teaching-second-edition-9780807750780

[10] Paris D. Culturally sustaining pedagogy: A needed change in stance, terminology, and practice. Educational Researcher, 2012, 41(3): 93-97. DOI: 10.3102/0013189X12441244.

[11] Kokotsaki D, Menzies V, Wiggins A. Project-based learning: A review of the literature. Improving Schools, 2016, 19(3): 267-277. DOI: 10.1177/1365480216659733.

[12] Wiggins G. The case for authentic assessment. Practical Assessment, Research, and Evaluation, 1990, 2(1): 2. DOI: 10.7275/ffb1-mm19.

[13] Gulikers JTM, Bastiaens TJ, Kirschner PA. A five-dimensional framework for authentic assessment. Educational Technology Research and Development, 2004, 52(3): 67-86. DOI: 10.1007/BF02504676.

[14] Dunlap RE, Van Liere KD, Mertig AG, et al. Measuring endorsement of the new ecological paradigm: A revised NEP scale. Journal of Social Issues, 2000, 56(3): 425-442. DOI: 10.1111/0022-4537.00176.

[15] Hollweg KS, Taylor JR, Bybee RW, et al. Developing a framework for assessing environmental literacy. North American Association for Environmental Education, 2011. Available from: https://cdn.naaee.org/sites/default/files/inline-files/devframewkassessenvlitonlineed.pdf

[16] UNESCO. Education for sustainable development: A roadmap. 2020. DOI: 10.54675/YFRE1448. Available from: https://unesdoc.unesco.org/ark:/48223/pf0000374802

[17] Design-Based Research Collective. Design-based research: An emerging paradigm for educational inquiry. Educational Researcher, 2003, 32(1): 5-8. DOI: 10.3102/0013189X032001005.

[18] Wang F, Hannafin MJ. Design-based research and technology-enhanced learning environments. Educational Technology Research and Development, 2005, 53(4): 5-23. DOI: 10.1007/BF02504682.

[19] Kemmis S, McTaggart R. The action research planner, 3rd ed. Deakin University, 1988. Available from: https://books.google.com/books/about/The_Action_Research_Planner.html?id=EkhLQAAACAAJ

MEDICAL STUDENTS' EVALUATION OF TEACHING SYSTEM: A BASIS FOR IMPROVING MEDICAL EDUCATION

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Abstract: A high-quality teaching system is pivotal to the cultivation high-quality talents. Whereas teachers play a critical role in improving the teaching quality, quality teaching feedback is an ingredient for teacher success. Therefore, a reasonable and robust evaluation method for a teaching system will help academics to continuously analyze their teaching content and methods thereby improve teaching quality. The quality of medical education is fundamental to the development of medical education. Medical education is crucial in developing advanced medical talents through training, and the education quality of medical students directly influences the quality of medical and healthcare practice in the future. At present, there is an upward trend in the implementation of the evaluation of the teaching system in medical schools of various universities. However, several shortcomings remain. This review analyzes and discusses approaches to establish a scientific and reasonable evaluation system for medical students, to provide new ideas for the construction of medical evaluation indicators as well as clear guidelines and directions for medical schools to carry out education and teaching reforms in the future.

Keywords: Medical students; Evaluation of teaching system; Student evaluations of teaching; Teaching quality; Management of teaching evaluation system

1 INTRODUCTION

The increasing demand to train many qualified medical talents to provide quality medical services and a healthy population inspired the development of medical education reform in China. An improvement in the quality of medical education is a fundamental guarantee of effective medical talent training, and the assessment and inspection of medical education ensure the improvement of the quality of medical education. Students directly participate in teaching activities, and student evaluations of teaching (SETs) are an important means to evaluate teaching quality [1, 2]. Although SETs were originally developed to assess courses and programs, they have also been used over the years to measure teaching effectiveness [3]. SETs are mainly used to identify problems in the teaching process in time to improve teachers' teaching skills, mobilize their initiative, enthusiasm, and creativity in teaching, enhance teaching ability and change teaching attitude [4]. Thus, medical educators should adopt SETs to improve their teaching ability and attitudes.

The current medical students' evaluation of the teaching system generally lacks a scientific and effective evaluation index system and method and pays insufficient attention to management tools of the evaluation system. This evaluation of the teaching method has a single function; it is only used as the main basis for the promotion of teachers and the implementation of "merit pay "[5]. This has weakened its diagnostic, regulatory, guidance, motivational, and improvement functions. In addition, most of the current evaluation of teaching systems used in medical schools cannot evaluate the evaluation subjects from a professional perspective, and rarely involve the knowledge, ability, and quality of teachers. The main problem is the lack of effective feedback and feedback delay [6]. Therefore, there is a need to combine the three levels, i.e., students, teachers, and school management, to develop an evaluation of a teaching system that is more conducive to improving the professional standards of medical students and standardizing the curriculum, to ensure training of qualified medical personnel.

2 OVERVIEW OF THE MEDICAL STUDENTS' EVALUATION OF THE TEACHING SYSTEM

2.1 Content of the Evaluation of Teaching

Content of the evaluation of teaching is the cornerstone of the evaluation of the teaching system, and good and reasonable medical assessment content is a prerequisite for medical students' evaluation of the teaching system. The content of teaching evaluation usually includes teaching attitude, teaching content, teaching philosophy, teaching methods, teaching level, and teaching management. A previous study investigating the criteria medical students value

and use when assessing teaching skills found that the four descriptive keywords that appeared most frequently were engagement, level of the learner, enthusiasm, and respect, which represented four themes, teaching methods, content, teacher personal attributes, learning environment [7]. The setting of teaching evaluation content should not only be reliable, effective, and consistent but also concise and sufficient. Formulating an effective and reliable questionnaire is an indispensable tool to make a good judgment on teachers' potential and ability [8].

Unlike other disciplines, the medical field is unique. The undergraduate medical student curriculum is composed of theoretical basic knowledge and clinical skills practice. The former focuses on the construction of the medical basic knowledge system, while the latter is the practical application of theoretical knowledge, including the use of laboratory instruments, medical technology hands-on practices, and direct interaction with patients in clinical settings. Therefore, the content of the medical students' evaluation of the teaching system should involve the assessment of teaching quality at both theoretical and practical levels. Based on the different teaching styles of academics, clinical teaching may be a more inherently subjective process, and therefore more aspects should be considered when designing the clinical teaching assessment criteria [9-11].

2.2 Evaluation of Teaching Methods

At present, medical students can evaluate teaching mainly using paper-based and paperless online evaluations. The specific process of paper-based evaluation includes the following: the teaching department sends the students the "Course Teaching Rating Form", students fill it out and submit it within the deadline, and the staff collects it for sorting and statistical analysis. The specific process of online evaluation is as follows: students log on to the evaluation website, select the course, score and evaluate and fill in suggestions, and complete the evaluation. With advances in mobile phone and internet technologies, more universities choose to use paperless online evaluation of teaching systems than the traditional paper-based evaluation method, which is limited by high cost, inefficiency, unreliable, low participation, etc. Online evaluation not only improves the efficiency of evaluation but also improves the reliability of evaluation results by using advanced algorithms [12, 13]. To ensure that every student actively participates in the evaluation, the university imposes sanctions on students who do not complete the evaluation within the specified time and disqualify them from taking classes in the next semester, to increase the participation rate of students and make the final data operable.

However, whether students should be anonymous in a teaching evaluation system remains controversial. A previous study compared the teaching performance of medical school faculty through anonymous and open assessments (where the evaluator's identity was revealed) and explored the barriers to open assessment. Results showed a statistically significant difference between open and anonymous assessments, with faculty members scoring lower on anonymous assessments. The greatest barrier to the validity of open assessment data was students' concern that the assessment results obtained by real names would affect their relationships with faculty, suggesting that students would be more honest in anonymous assessments. This study supports the use of anonymous assessment methods to more accurately reflect teaching performance [14]. However, in some cases, teachers who fairly award grades that do not meet students' expectations may score lower on anonymous assessments, which could limit the accuracy of anonymous assessments [15]. Although the study shows that this is not uncommon, students should be rightfully awarded what they deserve.

2.3 Time for Evaluation of Teaching

The student evaluation of the teaching system is generally implemented once a semester, before the end of the semester. The school will organize the distribution of relevant documents, students independently view the information of the instructor through the online evaluation system per the requirements of the document, and the instructor of the selected course makes a real evaluation [16]. The online evaluation system allows students to view the instructor's information and evaluate the instructor of their chosen course. In the School of Public Health and Basic Medicine of Jinan University, for example, the evaluation period is between the 14th and 18th week of each semester, towards the end of the course. This schedule not only prevents the final exam results from affecting the fairness of students' evaluations but also allows medical students to complete most of the courses and get a basic understanding of the course system before making their evaluations, thus ensuring the rationality and integrity of course evaluation. Research has shown that students' evaluations of courses and instructors are influenced, at least in part, by the grades they expect or receive[7]. Therefore, the evaluation scores should be released after the final exam results are announced to enhance object scoring.

2.4 Necessity and Purpose of the Evaluation of Teaching

Medicine is a highly specialized discipline, and the clinical aspects of knowledge are constantly changing with the advancement in the medical field. Therefore, clinical teaching in medical schools should be continuously updated and strengthened to enhance teaching quality [17]. In addition, some medical faculty members are physicians, with little teaching responsibilities and little or no training on how to be effective academics, and have little time to develop their teaching skills; hence, an effective and well-developed evaluation process could be valuable in improving the quality of clinical teaching[18-20].

SETs are a fundamental system for quality assurance of teaching in universities, and their establishment fully respects the subject position of students. Compared with teachers' mutual evaluation, experts' evaluation, and university leaders' evaluation, students play a more critical role in the evaluation of teachers' teaching quality as the subject and object of

teaching because they participate in the process of internal quality assurance and experience teachers' knowledge and style in the process of teaching [6, 21]. Effective SETs can not only help academics discover their strengths and weaknesses in the teaching process, to better summarize their teaching experience, improve their teaching methods and enhance the quality of teaching, but also strengthen the teaching monitoring system and improve the overall level of teaching[22-24]. A successful teacher evaluation process can also provide objective measures of teaching performance for performance evaluation and promotion decisions[25]. Therefore, establishing a comprehensive set of student evaluation systems for teaching quality in medical undergraduate education is an important method and means to comprehensively improve the teaching quality of medical schools, and it is of great significance to promote the development of medical education[26].

3 PROBLEMS IN THE MANAGEMENT OF THE TEACHING EVALUATION SYSTEM

SETs are one of the main means of teaching quality supervision in universities, and it is important to improve teaching quality and ensure the achievement of teaching objectives; thus, most medical schools are already implementing teaching evaluation. However, SETs are often, to some extent, limited during application. Besides, management and optimization of evaluation in universities still face several drawbacks as illustrated herein.

3.1 Content of Assessment is Fixed and the Way of Assessment is Single

The content of the current medical students' evaluation of the teaching system is mostly single and fixed, and uniform assessment entries are used in different medical courses, which cannot be set according to the characteristics of the courses and the course teachers. This may lead to homogenization, low relevance course evaluation, and uneven improvement effect on different courses, which cannot achieve comprehensive development. Most of the descriptions of assessment contents are focused on classroom teaching, which neglects the assessment of clinical teaching. Clinical instruction is very different from classroom instruction in that it involves multiple faculties and facilities, has a low student-to-faculty ratio, and uses various teaching methods (e.g., one-on-one tutorials, conferences, rounds, and simulations) [27]. Therefore, optimizing and improving the medical student assessment system must begin with eliminating the disadvantages of single assessment content.
Current teaching assessment methods lack diversified and flexible teaching methods. Most comprehensive universities only have a single way of online assessment for the simplification of procedures. However, the medical undergraduate curriculum is more complex than that of engineering, agriculture, arts, and sciences, and its complexity lies in the multi-level teaching methods, diversified teaching purposes, and numerous curriculums. Therefore, the overly simplified assessment method cannot provide detailed feedback on the training and management of medical students[22]. Moreover, since students are often bored with a large number of courses, the perfunctory evaluation is inevitable, leading to high or low overall grading and less meaningful suggestions, which limits the effectiveness of online evaluation [28].
The evaluation of competency-based higher education has become quite a hot topic in European Union countries. Its new concept of assessment is divided into three stages. The first stage assesses whether the competencies that students should acquire in the course are well defined. The second stage assesses the teaching and learning process and the competencies acquired by the students. The third stage assesses specific aspects of the teaching and learning process [29]. This evaluation of the teaching system not only evaluates the quality of teaching but also the actual gains made by the students in the learning process, which is a holistic evaluation system worthy of consideration.

3.2 Lack of Timeliness of Teaching Evaluation

Most of the assessment periods are set towards the end of the semester, affecting the timeliness of the assessment [30]. Due to the special nature of medical courses, different modules are mostly taught by teachers with different research directions, and hence a specialized course may be taught by a team of several academics [10]. Because the system only shows the name but not the photo of the instructors, students may not be impressed by the lectures after the semester, and some of them can only make vague scores based on their impressions, which may not guarantee the authenticity, accuracy, and reliability of the ratings [31]. Some studies have evaluated the efficiency of sampling and voluntary student samples for teacher evaluation, and the results showed that the sampling method can reduce the evaluation requirements for students, and there is little bias in the evaluation results from either method [32, 33]. Therefore, increasing the number of teacher evaluations per semester using sampling and voluntary student samples could help ensure the timeliness of the evaluations.

3.3 Inaccurate Positioning of the Evaluation Subject

Evaluations of teaching systems are often perceived as sensitive and controversial; questioning the validity of student evaluations of faculty teaching skills by administrations may trigger controversy [34-36]. An effective evaluation index system should be scientific and reasonable, assess all major aspects specified for teaching quality, and be completed with the active cooperation of students. However, the current evaluation indexes in major universities are often jointly formulated by the academic affairs office and other management departments and school expert supervisory groups, while neglecting students (who only passively cooperate with them) in the setting and weighting of the evaluation

indexes, thereby resulting in students' passive participation in teaching evaluation activities, which significantly affects evaluation results. For students, the evaluation process is their right and duty, and research shows that students are highly motivated by regular evaluations and are not biased by the difficulty of the subject itself or their interest in the process [37-39]. However, students' evaluation of courses and teachers are influenced, at least in part, by the amount of work they are required to do and the grades they expect or receive [40, 41]. Some students may be concerned that the results of the evaluation may affect their final grade and fail to fairly evaluate the course, which influences the efficacy of the evaluation system and its intended purpose of establishing a link between instructors and students [42].

3.4 Limitations in the Use of Assessment Results

The use of student evaluation results by schools directly affects the attitude of medical students to participate in the evaluation [43]. Some management departments do not handle the results of students' evaluations on time and conduct follow-up surveys and feedback. This makes the evaluation a formality and a state of coping, undermining students' opinions and suggestions, who gradually become disinterested. Teaching management departments are the custodians of all the evaluation results of teachers. Whereas teachers receive their evaluation results, there is no evaluation feedback for students. This kind of asymmetric information feedback may leave a negative impression on students. Collectively, these could lead to inaccurate, inefficient, and misleading evaluation results. All assessments in medical education require valid and reliable evidence to be interpreted meaningfully [44, 45].

Several other factors not limited to the performance of teachers exist and could influence the final evaluation results [46, 47]. College curriculum, environment, and psychological state of students all have an impact on the evaluation results. Thus, the evaluation results also reveal the problems of management, faculty, and students [48]. It is noteworthy that the ultimate goal of the evaluation is not only to get a statistical result but also to ensure the teaching effectiveness of teachers' and promote the development of teaching in the college. If the college does not have the resources to help teachers meet and exceed the standards required by summary assessment, it is fundamentally unreasonable to evaluate the teachers based on these standards [49].

4 SUGGESTIONS AND IMPROVEMENTS FOR THE MANAGEMENT OF MEDICAL STUDENTS' TEACHING EVALUATION SYSTEM

4.1 Recommendations

Overall, instructional assessment is challenging, rewarding, interesting, and transformative [50]. The main problems of the current teaching assessment system are the fixedness of the content of the assessment, the singularity of the assessment method, and the time-lag assessment. Through a careful review of "Comrade Li Keqiang's Important Guiding Ideas in the National Conference on the Reform and Development of Medical Education", "Opinions on the Evaluation of Undergraduate Teaching in General Higher Education Institutions" and "Several Opinions on the Overall Improvement of Higher Education Quality", and analysis of the current situation of domestic medical education, the following suggestions are made.

• Highlight the disciplinary characteristics of medical students' assessment programs, which must be different from those of other majors in comprehensive universities, optimize the same settings for the characteristics of both theoretical basic knowledge and clinical skills practice courses, propose differentiated designs, and set up student assessment programs in a reasonable and targeted manner.

• Provide a variety of assessment methods that focus on developing ways to facilitate student assessment of courses and on but not limited to online assessment. Parallel multiple methods of assessment, where students can selectively complete one form of assessment, ensure that the content of the assessment is uniform and varied.

• Improve the authenticity and accuracy of student evaluations and optimize the lag of course evaluations. The number of evaluations can be appropriately increased each semester. However, the number of items on each evaluation should be reduced to ease the burden on students and dampen the effect on their enthusiasm for evaluation.

• Improve the reward system by including the completion of teaching evaluation into the basis for students' merit assessment, and appropriately reward students with high cooperation to improve the enthusiasm of students and the reliability of the evaluation [51].

• Complete a phase-course evaluation when anonymously publishing statistical data; timely notify teachers with poor teaching quality and adjust their teaching style to further optimize the lag of evaluation [14].

4.2 Specific Processes for Improving the Evaluation of a Teaching System Model

The model of medical students' assessment system in any form of improvement should be an organic combination of students, lecturers, and supervisors (faculty), with no party missing. The improved assessment model should emphasize its feasibility and scientific and practical significance and eliminate formalism, prioritize students, and always be adjustable (Figs. 1 and 2) [52].
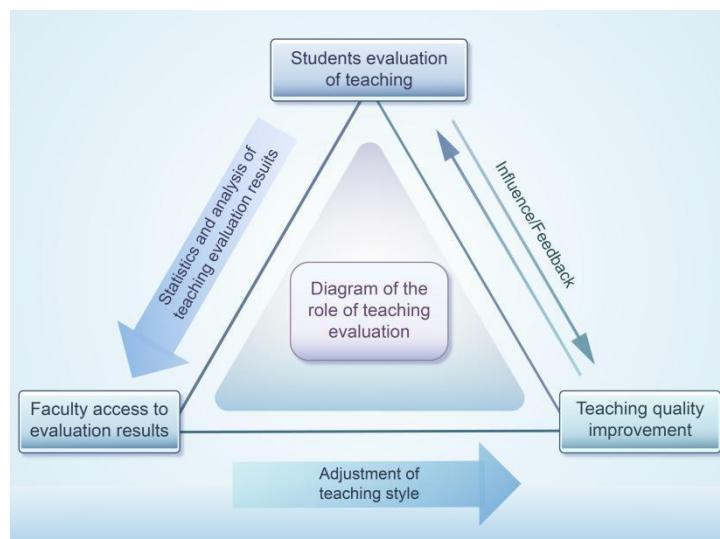
**Figure 1** Schematic Diagram of the Role of Teaching Evaluation
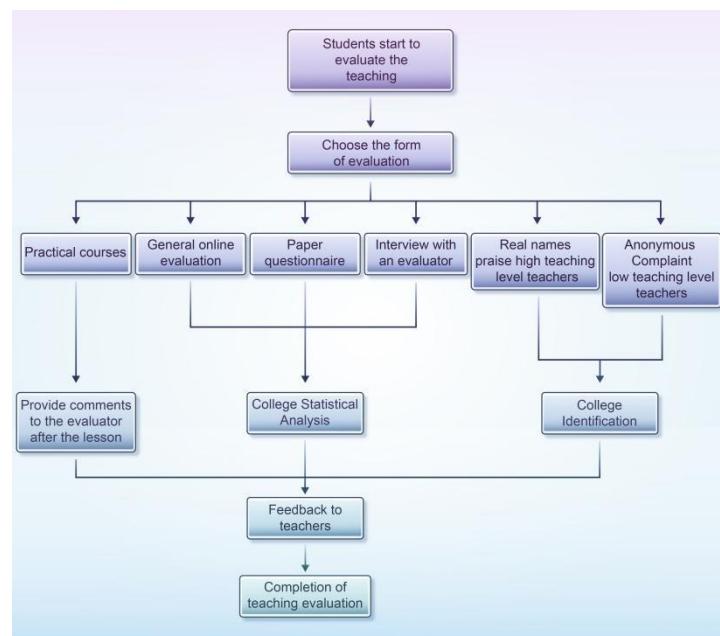
Figure 2 Flow Chart of Student Evaluation

5 CONCLUSION

In summary, to solve the current problems in the medical students' evaluation of the teaching system, firstly, pay sufficient attention to the composition of the evaluation system and analyze and optimize its content, mode, and time components in turn. Secondly, utilize the results of students' evaluation and establish the mechanism of evaluation between students, teachers, and colleges in time, which plays a significant role in improving the education quality of teachers and teaching quality. However, the current medical students' evaluation of the teaching system is facing a myriad of setbacks; therefore, it is imperative to be abreast with the requirements of the medical undergraduate course syllabus and grasp the specific learning situation of medical students, to effectively carry out medical assessment reform and promote the reform of the whole medical training talent program. As an important way of teaching quality monitoring and a scientific medical student assessment system, SETs can boost the development of the national medical profession and continuously ensure qualified and excellent medical talents.

COMPETING INTERESTS

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AUTHORS' CONTRIBUTIONS

All authors contributed to the concept and structure of the paper. Lizhi Chen wrote the first draft of the manuscript that was then critically revised by Jie Shan, Jiayi Zhang, Yingjun Zhu, Yue Zhou, and Shuang Liu. Jiayi Zhang finished making article figures and performed the final edit prior to submission. All authors approved the final version for publication and agree to be accountable for all aspects of the work.

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REFERENCES

[1] Marsh HW, Fleiner H, Thomas CS. VALIDITY AND USEFULNESS OF STUDENT EVALUATIONS OF INSTRUCTIONAL QUALITY. Journal of Educational Psychology, 1975, 67: 833-839.

[2] Kim SM, Park SG, Jee YK, et al. Perception and attitudes of medical students on clinical clerkship in the era of the Coronavirus Disease 2019 pandemic. Medical education online, 2020, 25, 1809929.

[3] Constantinou C, Wijnen-Meijer M. Student evaluations of teaching and the development of a comprehensive measure of teaching effectiveness for medical schools. BMC medical education, 2022, 22, 113.

[4] Ploteau S, Winer N, Barrier J, et al. Evaluation of the instruction and the instructors by the students during a clinical training period in a gynecology and obstetrics unit. Journal de gynecologie, obstetrique et biologie de la reproduction, 2007, 36, 807-816.

[5] Morgan H, Purkiss J, Porter A, et al. Student Evaluation of Faculty Physicians: Gender Differences in Teaching Evaluations, 2016, 25, 453-456.

[6] Hunukumbure AD, Horner PJ, Fox J, et al. An online discussion between students and teachers: a way forward for meaningful teacher feedback? BMC medical education, 2021, 21, 289.

[7] Pettit J, Axelson R, Ferguson K, et al. Assessing effective teaching: what medical students value when developing evaluation instruments, 2015, 90, 94-99.

[8] Al-Rubaish AM, Abdel Rahim SI, Hassan A, et al. Developing questionnaires for students' evaluation of individual faculty's teaching skills: A Saudi Arabian pilot study. J Family Community Med, 2010, 17, 91-95.

[9] Conigliaro RL, Stratton TD. Assessing the quality of clinical teaching: a preliminary study. Medical education, 2010, 44, 379-386.

[10] Hwang JE, Kim NJ, Song M, et al. Individual class evaluation and effective teaching characteristics in integrated curricula. BMC medical education, 2017, 17, 252.

[11] Schiekirka S, Raupach T. A systematic review of factors influencing student ratings in undergraduate medical education course evaluations. BMC Medical Education, 2015, 15, 30.

[12] Xu X, Liu F. Optimization of online education and teaching evaluation system based on GA-BP neural network. Computational Intelligence and Neuroscience, 2021, 8785127.

[13] Rosenberg ME, Watson K, Paul J, et al. Development and implementation of a web-based evaluation system for an internal medicine residency program. Academic Medicine, 2001, 76, 92-95.

[14] Afonso NM, Cardozo LJ, Mascarenhas OA, et al. Are anonymous evaluations a better assessment of faculty teaching performance? A comparative analysis of open and anonymous evaluation processes. Family Medicine, 2005, 37, 43-47.

[15] Tucker B. Student evaluation surveys: anonymous comments that offend or are unprofessional. Higher Education, 2014, 68, 347-358.

[16] Berk RA. Top five flashpoints in the assessment of teaching effectiveness. Medical Teacher, 2013, 35, 15-26.

[17] Lewisson N, Hellgren L, Johansson J. Quality improvement in clinical teaching through student evaluations of rotations and feedback to departments. Medical Teacher, 2013, 35, 820-825.

[18] Srinivasan M, Li ST, Meyers FJ, et al. "Teaching as a competency": competencies for medical educators. Academic Medicine, 2011, 86, 1211-1220.

[19] van den Berg BA, Bakker AB, Ten Cate TJ. Key factors in work engagement and job motivation of teaching faculty at a university medical centre. Perspectives on Medical Education, 2013, 2, 264-275.

[20] van Bruggen L, Ten Cate O, Chen HC. Developing a novel 4-C framework to enhance participation in faculty development. Teaching and Learning in Medicine, 2020, 32, 371-379.

[21] Lidice A, Saglam G, editors. Using students' evaluations to measure educational quality. Proceedings of the Akdeniz Language Studies Conference, Antalya, TURKEY. 2012.

[22] Vaughan B. Clinical educator self-efficacy, self-evaluation and its relationship with student evaluations of clinical teaching. BMC Medical Education, 2020, 20, 347.

[23] Boerebach BC, Arah OA, Heineman MJ, et al. The impact of resident- and self-evaluations on surgeon's subsequent teaching performance. World Journal of Surgery, 2014, 38, 2761-2769.

[24] Julian K, Appelle N, O'Sullivan P, et al. The impact of an objective structured teaching evaluation on faculty teaching skills. Teaching and Learning in Medicine, 2012, 24, 3-7.

[25] Woods NN. Evaluation matters: lessons learned on the evaluation of surgical teaching. The Surgeon, 2011, 9(Suppl 1): S43-S44.

[26] Hsieh MC, Chen TY. Promoting innovation in the objective structured teaching examination and feedback: clustering teachers to aid teaching evaluation. Medical Education Online, 2019, 24, 1620544.

[27] Love DW, Heller LE, Parker PF. The use of student evaluations in examining clinical teaching in pharmacy. Drug Intelligence & Clinical Pharmacy, 1982, 16, 759-764.

[28] Uijtdehaage S, O'Neal C. A curious case of the phantom professor: mindless teaching evaluations by medical students. Medical Education, 2015, 49, 928-932.

[29] Bergsmann E, Schultes MT, Winter P, et al. Evaluation of competence-based teaching in higher education: from theory to practice. Evaluation and Program Planning, 2015, 52, 1-9.

[30] Canaday SD, Mendelson MA, Hardin JH. The effect of timing on the validity of student ratings. Journal of Medical Education, 1978, 53, 958-964.

[31] Stratton TD, Witzke DB, Freund MJ, et al. Validating dental and medical students' evaluations of faculty teaching in an integrated, multi-instructor course. Journal of Dental Education, 2005, 69, 663-670.

[32] Kreiter CD, Lakshman V. Investigating the use of sampling for maximising the efficiency of student-generated faculty teaching evaluations. Medical Education, 2005, 39, 171-175.

[33] Carline J, Scher MJJ. Comparison of course evaluations by random and volunteer student samples. Journal of Medical Education, 1981, 56, 122-127.

[34] Greenwald AG. Validity concerns and usefulness of student ratings of instruction. American Psychologist, 1997, 52, 1182-1186.

[35] Nemec EC, Baker DM, Zhang D, et al. Development of valid and reliable tools for student evaluation of teaching. Currents in Pharmacy Teaching and Learning, 2018, 10, 549-557.

[36] Leamon MH, Fields L. Measuring teaching effectiveness in a pre-clinical multi-instructor course: a case study in the development and application of a brief instructor rating scale. Teaching and Learning in Medicine, 2005, 17, 119-129.

[37] Pfeifer MP, Peterson HR. The influence of student interest on teaching evaluation. Journal of General Internal Medicine, 1991, 6, 141-144.

[38] Hill DA. SCORPIO: a system of medical teaching. Medical Teacher, 1992, 14, 37-41.

[39] Murray D, Boothby C, Zhao H, et al. Exploring the personal and professional factors associated with student evaluations of tenure-track faculty. PLOS One, 2020, 15, e0233515.

[40] Stroebe W. Why good teaching evaluations may reward bad teaching: on grade inflation and other unintended consequences of student evaluations. Perspectives on Psychological Science, 2016, 11, 800-816.

[41] Mendelson MA, Canaday SD, Hardin JH. The relationship between student ratings of course effectiveness and student achievement. Medical Education, 1978, 12, 199-204.

[42] Snell L, Tallett S, Haist S, et al. A review of the evaluation of clinical teaching: new perspectives and challenges. Medical Education, 2000, 34, 862-870.

[43] McClain L, Gulbis A, Hays D. Honesty on student evaluations of teaching: effectiveness, purpose, and timing matter! Assessment & Evaluation in Higher Education, 2018, 43, 369-385.

[44] Beckman TJ, Ghosh AK, Cook DA, et al. How reliable are assessments of clinical teaching? A review of the published instruments. Journal of General Internal Medicine, 2004, 19, 971-977.

[45] Downing SM. Reliability: on the reproducibility of assessment data. Medical Education, 2004, 38: 1006–1012.

[46] Zhang Z, Wu Q, Zhang X, et al. Barriers to obtaining reliable results from evaluations of teaching quality in undergraduate medical education. BMC Medical Education, 2020, 20, 333.

[47] Dodeen H. Validity, reliability, and potential bias of short forms of students' evaluation of teaching: the case of UAE University. Educational Assessment, 2013, 18, 235-250.

[48] Mårtenson D, Nystrup J. Evaluation and consequences of teaching competence: Scandinavian developments. Medical Education, 1984, 18, 394-400.

[49] Elzubeir M, Rizk D. Evaluating the quality of teaching in medical education: are we using the evidence for both formative and summative purposes? Medical Teacher, 2002, 24, 313-319.

[50] LaVelle JM, Lovato C, Stephenson CL. Pedagogical considerations for the teaching of evaluation. Evaluation and Program Planning, 2020, 79, 101786.

[51] Jones RF, Froom JD. Faculty and administration views of problems in faculty evaluation. Academic Medicine, 1994, 69, 476-483.

[52] Heckman K, Kim R, Lee A, et al. Surgeons have an opportunity to improve teaching quality through feedback provision. Annals of Surgery, 2018, 229, 164-168.