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Exploring Transformation of AI-Empowered Teaching Models in Higher Education: A Case Study of New Energy Science and Engineering

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Abstract

Against the backdrop of the global digital transformation in education and the deep integration of artificial intelligence (AI) technology, AI-empowered higher education has become a significant trend in international educational reform. Based on the demands of global energy transition and industrial transformation, this paper focuses on the interdisciplinary field of New Energy Science and Engineering, systematically reviewing the international research context, current developments, and practical challenges of AI-empowered teaching. Taking the "Hydrogen Energy and Fuel Cell Technology" course as an example, a teaching reform path centered on "value integration, environment reconfiguration, and role transformation" is proposed. By promoting systematic innovation in teaching philosophy, learning environment, and the roles of teachers and students, this study explores the construction of a human-centered, human-machine collaborative educational paradigm, providing theoretical reference and practical cases for the digital development and teaching model transformation of global higher education.

Keywords

Artificial intelligence; Human-machine collaboration; New energy science and engineering; Teaching model; Teaching reform

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1. Introduction

In recent years, the application of artificial intelligence (AI) technology in the global education sector has continuously deepened, becoming a significant force in promoting educational modernization and digital transformation [1]. International organizations such as UNESCO and the World Economic Forum have repeatedly emphasized that emerging technologies, represented by AI, are reshaping the landscape of higher education and fostering fundamental changes in teaching paradigms [2]. Against this backdrop, many countries have incorporated AI in education into their national strategies, aiming to build more personalized, ubiquitous, and intelligent educational ecosystems [3].

As a key interdisciplinary field addressing global climate change and promoting the transformation of energy structures, New Energy Science and Engineering is characterized by rapid knowledge iteration and strong practical demands, which pose new challenges to traditional teaching models [4]. Leveraging its advantages in adaptive learning, simulation, data insight, and intelligent assessment, AI technology has opened new pathways for cultivating high-quality talents with cross-disciplinary expertise in "Energy + AI" [5]. However, the integration of AI and education globally remains in a phase of exploration and refinement, facing multiple challenges such as insufficient conceptual alignment, outdated teaching methods, a mismatch in digital literacy between teachers and students, and inadequate technological integration environments [6]. Therefore, this paper aims to systematically review current international research progress and practical difficulties, using a specific course as a practical vehicle to construct a scalable AI-empowered teaching model framework, providing an internationally informed reference for teaching reform in related disciplines.

2. Research review and practical challenges of AI-empowered teaching

2.1. Research background: Dual drivers of global education reform and professional development

From a global trend perspective, promoting the deep integration of AI and education has become an important strategy for many countries to enhance education quality and foster educational equity [7]. Cao *et al.* pointed out that the rapid development of artificial intelligence is driving the digital transformation of teaching, and its potential in personalized teaching is increasingly being recognized [8]. In the assessment of digital education's impact, Kingsley et al. analyzed its potential obstacles, challenges, and opportunities, thereby highlighting its significance for sustainable education and practices [9].

From the perspective of professional development needs, the global new energy industry is rapidly evolving towards digitalization and intelligence, with AI applications becoming increasingly widespread in areas such as energy demand forecasting, grid optimization, fault diagnosis, and operation maintenance [10,11]. This necessitates that talent cultivation in the new energy field keeps pace with technological advancements, integrating AI thinking and skills into the curriculum system to equip students for future energy systems characterized by data-driven and intelligent decision-making. Against this backdrop, the specific demands for AI-empowered teaching are reflected in: enhancing the precision and personalization of the teaching process; adapting to rapid technological iterations in the industry; cultivating interdisciplinary composite talents; and driving the continuous innovation and structural optimization of the education system itself [12,13].

2.2. Domestic and international practices and integration challenges

Leading universities domestically and internationally have made significant progress in the field of AI-empowered teaching. For example, Stanford University offers interdisciplinary courses in "AI + Energy," using virtual laboratories to allow students to design and optimize renewable energy systems; Tsinghua University has established a smart teaching platform that enables personalized learning path recommendations and intelligent assessment; RWTH Aachen University in Germany applies AR/VR technology to energy engineering practical training, significantly enhancing students' practical abilities. These practices have effectively promoted educational equity and resource sharing. However, deep-level integration still faces four major challenges:

(1) A contradiction exists between the traditional large-scale, standardized teaching philosophy and the demand for personalized, precise development supported by AI. Many teachers still view AI as an auxiliary tool rather than a driver of teaching paradigm transformation, failing to fundamentally reconstruct teaching objectives and evaluation systems. Balancing the "rationality" of technological tools with the essential value of education in "cultivating people," and avoiding the pitfall of "data-centric bias," is a primary challenge;

(2) Traditional teaching modes is confined by fixed time and space and uniform content, struggling

to meet students' needs for dynamic, vast, and personalized knowledge. Although online forms like MOOCs and micro-lectures partially break through spatiotemporal limitations, knowledge transfer remains largely one-way indoctrination. While AI technology can break spatiotemporal constraints, how to organically integrate it with traditional classrooms to form a blended teaching approach with online-offline interaction, achieving the organic combination of knowledge internalization and ability development, still requires in-depth exploration;

(3) As AI can undertake tasks such as knowledge impartation and homework grading, the role of teachers must inevitably transform. Teachers need to transition from "knowledge authorities" to designers, guides, and motivators of student learning, which places higher demands on their innovative thinking, critical thinking, and human-machine collaboration skills. Currently, university teachers generally lack AI literacy training, often feeling at a loss when faced with intelligent teaching environments;

(4) The existing physical teaching environment is ill-equipped to support the immersive, interactive, and contextualized learning advocated by AI technology. Most classrooms still primarily feature fixed layouts with a podium and desks, lacking infrastructure such as smart terminals, sensing equipment, and high-speed networks. Constructing an intelligent teaching environment that enables virtual-real integration and supports embodied cognition is fundamental to ensuring the implementation of new models.

3. Research approach, content, and methodology: Constructing systemic reform framework for AI empowerment

3.1. Research approach

This study takes the innovation of talent cultivation models in higher education under the background of artificial intelligence as its macro-direction, and uses the core course "Hydrogen Energy and Fuel Cell Technology" in the New Energy Science and Engineering major as its micro-level practical vehicle. The course content covers three key technical chains: "hydrogen production, hydrogen storage, and hydrogen utilization," characterized by its theoretical depth, strong practical focus, interdisciplinary nature, and rapid technological updates. This research intends to carry out systematic and refined AI-empowered teaching reform through three dimensions: exploring an intelligent educational model for the teaching philosophy, making diversified and continuous improvements to the learning environment, and enhancing individual faculty capacity.

This research follows the pathway of "problem-oriented-theory-building-practical validation-iterative optimization." It begins with an in-depth analysis of the practical challenges faced in the teaching of the New Energy major. Subsequently, based on constructivist learning theory, embodied cognition theory, and human-machine collaboration theory, a framework for an AI-empowered teaching model is constructed. This is followed by validating the effectiveness of the framework through course implementation, and finally, engaging in continuous optimization based on practical feedback. This approach ensures a close integration of theoretical innovation and practical exploration, enabling the study to both grasp the macro-level direction of educational reform and address specific teaching problems at the micro level.

3.2. Refined design of research content and methodology

3.2.1. Maintaining educational logic of value integration: Forming an AI-empowered teaching philosophy

To establish a teaching perspective that unifies the instrumental rationality of technological tools with the value rationality of engineering literacy within the comprehensive knowledge system of the "hydrogen production-hydrogen storage-hydrogen utilization" chain. It is essential to fully leverage the instrumental value of AI technology in enhancing teaching efficiency and expanding educational boundaries, while steadfastly adhering to the value pursuits of engineering education in cultivating innovative spirit, practical ability, and social responsibility. The specific pathways and methods are as follows:

(1) Deconstruction of course objectives and content: Conduct a detailed analysis of the three main course modules, as shown in **Figure 1**;
   (i) Hydrogen production technology module: the educational value of this module lies in cultivating students' life cycle assessment thinking and sustainable development perspective. In the teaching process, AI-driven life cycle assessment tools can be introduced, allowing students to visually compare the carbon emissions, energy consumption, and economics of different hydrogen production pathways, thereby deepening their understanding of sustainable development concepts;
   (ii) Hydrogen storage technology module: the educational value of this module lies in cultivating students' engineering trade-off thinking and safety awareness. Through AI-constructed knowledge graphs for hydrogen storage safety, students can systematically understand the safety boundaries and accident cases of various hydrogen storage technologies, and conduct hidden hazard identification training in virtual environments, thereby establishing a solid safety awareness;
   (iii) Hydrogen utilization technology module: the educational value of this module lies in cultivating students' system integration capabilities and innovative application thinking. Using AI-assisted design tools, students can independently design fuel cell systems and validate their performance through digital twin technology, fostering the ability to solve complex engineering problems in this process;

(2) Multi-subject participation mechanism: Organize professional teachers, educational technology experts, hydrogen energy enterprise engineers and senior students to conduct discussions around the teaching of the above technical points. The discussion process is divided into three stages, as shown in **Figure 2**. This mechanism ensures that the teaching reform aligns with technological development trends while also meeting the fundamental requirements of talent cultivation;

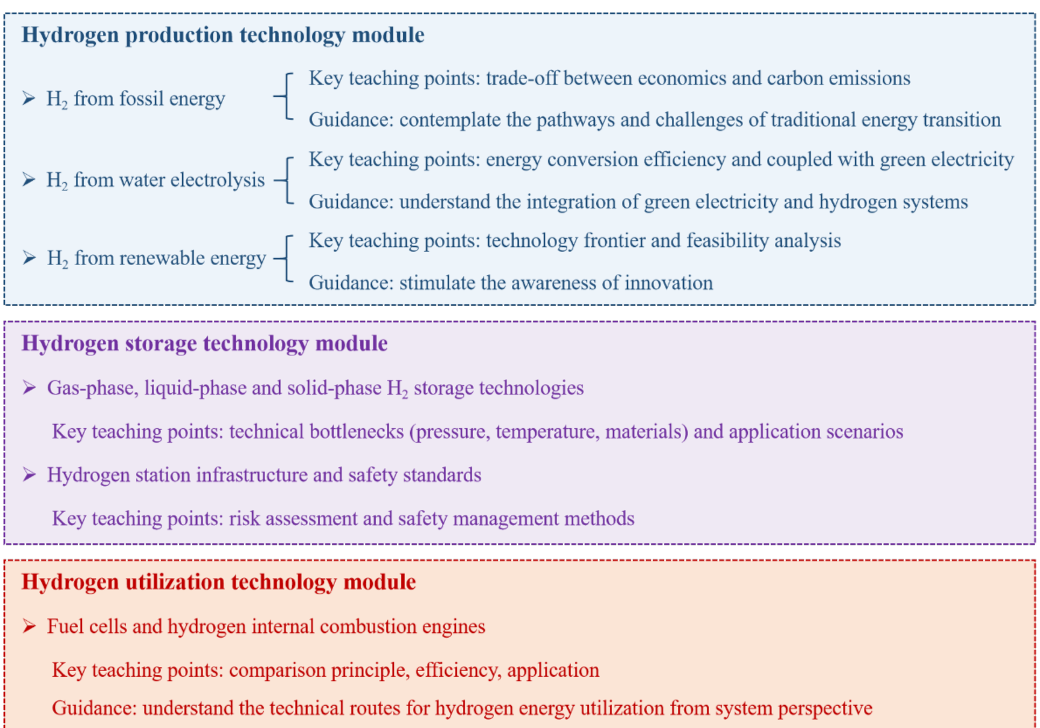

Figure 1. Deconstruction of course objectives and content.

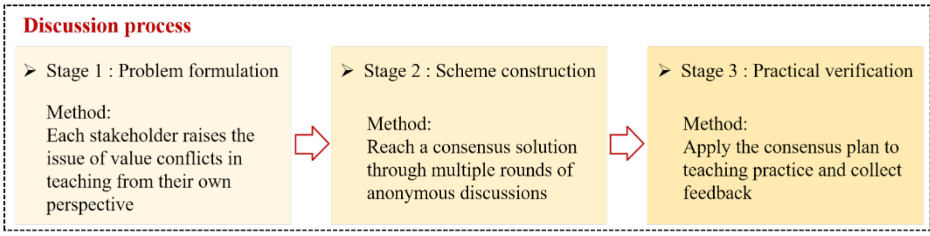

Figure 2. Multi-subject participation mechanism.

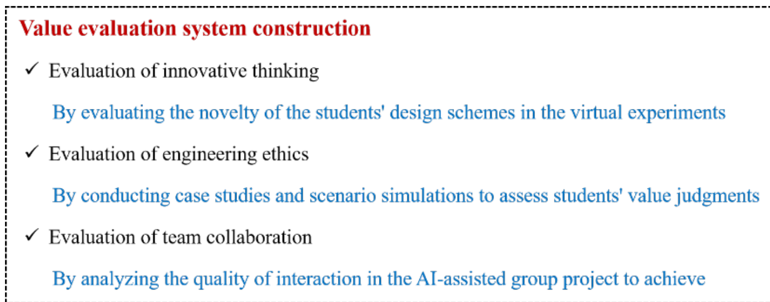

Figure 3. Value evaluation system construction.

For example, when teaching "fuel cells," AI can quickly simulate and demonstrate the performance curves of the fuel cell stack under different operating parameters. However, the core of teaching must guide students to understand the underlying principles such as its electrochemical reaction mechanism and membrane electrode degradation mechanisms, and to discuss practical challenges like cost and durability, thereby cultivating students' critical thinking and ability to solve complex engineering problems, and avoiding them becoming mere "black box" operators. To this end, a tripartite teaching segment of "principle-simulation-analysis" can be designed by explaining the basic principles through traditional teaching; then, use AI simulation to demonstrate performance variations; finally, guide students to analyze the scientific questions behind the simulation results, ensuring that technological tools serve deep learning;

(3) Value evaluation system construction: establish a diversified evaluation system that integrates technical capability and humanistic literacy. In addition to assessing the degree of knowledge acquisition through traditional means, incorporate AI-assisted formative evaluation, as shown in **Figure 3**. This evaluation system guides students to value both technical improvement and literacy development, achieving an organic unity of instrumental rationality and value rationality.

3.2.2. Developing digital teaching resources to create an AI-empowered teaching environment

To construct immersive and interactive virtual simulation teaching scenarios for course content that involves high cost, high risk, or high complexity, thereby achieving embodied cognition. By creating learning situations close to real engineering environments, students can construct knowledge and develop abilities through practice. The specific pathways and methods are as follows:

(1) Pain point identification and scenario design: Precisely identify teaching difficulties within the course that are suitable for intervention using AI and Virtual Simulation (VR/AR), as shown in **Figure 4**;

(i) For high-risk operations, simulation systems should be developed. These simulation systems should include complete job process training, handling of abnormal situations, and emergency accident response modules. Through multisensory feedback, it enhances the sense of immersion, enabling students to form a profound sense of safety in "actual experience";

(ii) For the abstract microscopic principles, visualization models should be developed. These models should support multi-scale presentation (from macroscopic devices to molecular and atomic levels), dynamic process simulation (such as proton transport pathways), and real-time parameter adjustment (such as the influence of temperature and humidity on the conduction rate), helping students build intuitive physical images;

(iii) For the integration and optimization of complex systems, a "digital twin" simulation platform should be constructed. This platform should integrate physical models, data-driven models and optimization algorithms, and support the entire process of system design, operation simulation and performance evaluation, allowing students to experience a complete engineering practice;

(2) Resource development and technology integration: Establish a five-step development process: "demand analysis-prototype development-expert review-pilot application-iterative optimization" to ensure the quality and applicability of digital resources. Technically, utilize AI to enable intelligent tutoring and personalized content recommendation. Simultaneously, focus on the organic integration with traditional teaching resources, forming a closed-loop learning environment of "offline theoretical instruction-online preview/review-virtual practical training;"

(3) Implementation and evaluation: Adopt a design-based research approach to iteratively develop and refine the virtual scenarios through teaching practice. Each implementation cycle includes a preparation phase (analysis of teaching objectives, technical solution design), an implementation phase (organization of teaching activities, data collection), an analysis phase (effect evaluation, problem identification), and an optimization phase (solution revision, resource updating). Evaluate the effectiveness in enhancing students' depth of understanding, memory retention, and practical ability through pre- and post-questionnaires, interviews, and analysis of operational data. Evaluation dimensions include: degree of knowledge mastery (via standardized tests), level of skill improvement (via practical assessments), changes in learning motivation (via scales), and development of thinking patterns (via interview analysis).

3.2.3. Fully leveraging human-machine synergy: Shaping AI-empowered teacher role

To leverage AI-driven data for decision-making, enabling dynamic adjustment of teacher roles and precise refinement of teaching strategies. Establish a collaborative division of labor characterized by "AI handles routine tasks-teachers focus on innovation," fully leveraging their respective strengths to enhance teaching effectiveness. The specific pathways and methods are as follows:

(1) Diversified teaching and data collection: Employ a mix of teaching models throughout the instructional process, such as the flipped classroom (for foundational knowledge transmission), project-based learning, and virtual

- **High-risk operation**
  - Knowledge point: stress analysis of high-pressure gaseous hydrogen storage tanks
  - Method: develop VR simulation for security training
- **Microscopic principles**
  - Knowledge point: proton conduction mechanism in proton exchange membrane
  - Method: develop an AR visualization model for the microscopic world
- **Complex system**
  - Knowledge point: dynamic matching and energy efficiency optimization of wind-hydro hybrid system
  - Method: build a "digital twin" simulation platform

Figure 4. Pain point identification and scenario design.

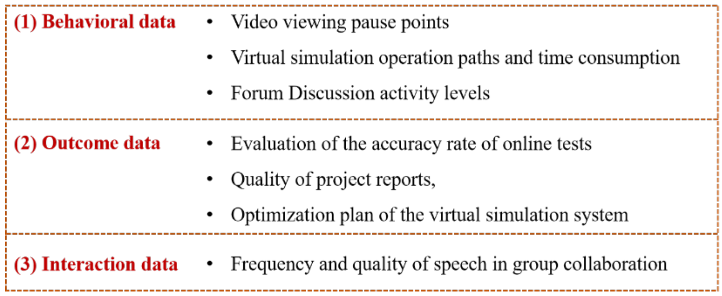

Figure 5. Diversified teaching and data collection.

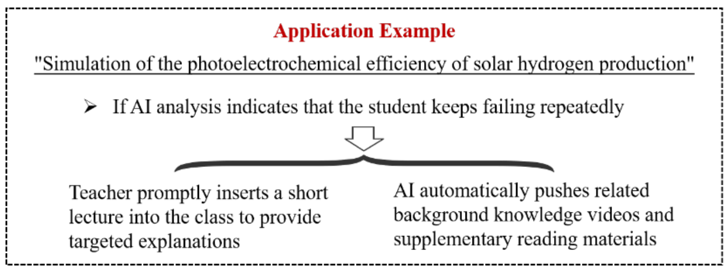

Figure 6. Feature analysis and teaching decision-making case.

simulation experiments. During these activities, multi-dimensional data is collected unobtrusively and throughout the process, as shown in **Figure 5**; Data collection should adhere to the principles of “minimally necessary” and “informed consent,” ensuring adequate protection of student privacy. Concurrently, establish a data quality management mechanism, including data cleaning, outlier handling, and missing value imputation, to ensure the reliability of data analysis.

(2) Feature analysis and teaching decision-making: Employ data mining techniques to perform feature analysis on the aforementioned datasets. Use cluster analysis to identify different types of learners (e.g., surface learners, deep learners, practice-oriented learners, etc.). Use association rule mining to discover intrinsic links between learning behaviors and outcomes. Use sequence analysis to reveal student learning path preferences. One application example as shown in **Figure 6**;

(3) Teacher professional development support: Establish an “AI literacy enhancement program” to help teachers adapt to their new roles. The program should include: technical training (use of AI tools, basics of data analysis), pedagogical updates (design of blended learning, organization of project-based learning), and collaboration skills development (human-machine collaboration, team teaching). Support teacher professional growth through various formats like workshops, teaching research communities, and instructional consulting;

(4) Continuous improvement loop: Based on the analysis reports provided by the AI, teachers summarize the effectiveness of different teaching models (e.g., pure theoretical lecture, pure virtual simulation, project-based learning) on student mastery of different knowledge types (e.g., conceptual knowledge, procedural knowledge, system design knowledge). This provides a scientific basis for the continuous improvement of the next course iteration. Furthermore, establish a teacher-AI collaborative teaching research mechanism where teachers translate teaching experience into optimization suggestions for AI algorithms, and the AI translates data analysis into supporting information for teaching decisions, achieving genuine “teaching determined by learning” and “human-machine collaborative teaching research.”

3.2.4. Building multi-dimensional assessment system to ensure quality of AI-empowered teaching

To establish a multi-dimensional assessment system that integrates formative and summative assessment, supplements quantitative with qualitative methods, and coordinates machine evaluation with teacher evaluation, thereby comprehensively reflecting the development of students' knowledge, abilities, and literacy. The specific pathways and methods are as outlined:

(1) Utilize AI technology to enable continuous tracking and dynamic evaluation of the learning process. This includes knowledge mastery evaluation, conducted through online quizzes and assignment analysis; ability development evaluation, conducted through the analysis of virtual experiment operations and project process records; literacy cultivation evaluation, conducted through the analysis of learning behavior data and mining of interaction content. AI can automatically generate learning profiles, providing a visual representation of students' strengths and weaknesses;

(2) For project-based learning outcomes, implement a dual evaluation mechanism involving AI initial review and teacher re-evaluation. AI is responsible for evaluating the completeness, standardization, and basic metrics of the outcomes. The teacher focuses on evaluating the innovation, practicality, and depth of thinking demonstrated in the outcomes. Simultaneously, introduce peer assessment and self-assessment mechanisms to cultivate students' metacognitive abilities and critical thinking;

(3) Evaluate students' awareness of engineering ethics and social responsibility through methods such as scenario-based judgment questions, case analysis tasks, and ethical discussions. AI can provide a rich repository of assessment scenarios and cases, and automatically analyze students' value orientations. The teacher, through in-depth interviews and observations, evaluates the maturity of students' value judgments;

(4) Establish a closed-loop mechanism of "assessment-feedback-improvement". AI automatically generates personalized learning reports, providing students with improvement suggestions. Teachers adjust teaching strategies based on the overall class assessment results. Educational administrators optimize curriculum design and resource allocation using macro-level assessment data.

4. Conclusion

The empowerment of higher education by artificial intelligence is far from a mere technological add-on; it represents a profound transformation touching the very core of education. For cutting-edge interdisciplinary fields such as New Energy Science and Engineering, this transformation presents both a challenge and a significant opportunity. The systemic reform framework proposed in this paper, anchored in "value integration as the soul, environment reconfiguration as the foundation, and role transformation as the essence", aims to return to the fundamental mission of fostering virtue and cultivating talents in education. It seeks to fully leverage the efficacy of AI technology while steadfastly upholding the humanistic warmth and value guidance inherent in education. Through the pioneering pilot implementation in the "Hydrogen Energy and Fuel Cell Technology" course, we aspire to explore a scalable and transferable pathway for intelligent talent cultivation, thereby contributing to the high-quality development of higher education.

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Disclosure statement

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