

Exploration of University Teachers' Digital Literacy and Enhancement Pathways in the Context of Virtual Teaching and Research Communities: A Case Study of the Energy and Power Engineering Major

Shiyuan Wang, Huifan Zheng*, Guoji Tian, Haofei Zhang

Zhongyuan University of Technology, Zhengzhou, 450000, China

*Corresponding author: 5823@zut.edu.cn

Abstract: In the context of the deep integration of intelligent digital technologies and higher education, virtual teaching and research communities serve as novel grassroots teaching organizations, providing a crucial platform for teacher development. Teachers' digital literacy directly determines the quality of these communities, yet they currently face challenges such as weak digital awareness, gaps in the application of technologies like energy system simulation, and a disconnect between training and professional practice. Based on the five-dimensional framework of the Ministry of Education's "Teacher Digital Literacy" standards, this study, taking the Energy and Power Engineering major as an example, proposes three enhancement pathways: strengthening digital awareness to promote teachers' proactive adaptation to the "teacher-machine-student" tertiary educational ecosystem transformation; constructing a personalized training system that leverages national, regional, and school-level resources to conduct direction- and level-specific "clinical-style" practical training; and innovating incentive mechanisms by integrating institutional evaluation, tiered certification, and honor-based recognition to link digital course development with Energy and Power industry certification, forming a closed loop of "evaluation-incentive-development." The study emphasizes that enhancing digital literacy should be guided by the objective of cultivating intelligent Energy and Power talents and realized through virtual teaching and research communities to achieve professional digital transformation.

Keywords: Energy and Power Engineering, digital technology, virtual teaching and research community, digital literacy

1. Introduction

At present, the development and integration of digital technologies represented by artificial intelligence, big data, and cloud computing reflect the rapid and innovative advancement of Internet information technologies, profoundly influencing societal development and increasingly permeating higher education. These technologies are reshaping the higher education ecosystem with unprecedented depth and breadth. Under the national "Dual-Carbon" strategy, energy and power systems are undergoing threefold transformations—digitalization, low-carbonization, and intelligentization. Multi-energy flow optimization driven by digital twins and AI-enabled upgrades of power equipment have become core directions for professional development, making intelligent energy and power an unstoppable trend. The Energy and Power Engineering major urgently needs to integrate with intelligent digital technologies to align with the development of higher education. Virtual teaching and research communities represent an innovative form of grassroots teaching organization in the digital era, aiming to enhance teachers' instructional competencies and providing new platforms and opportunities for Energy and Power Engineering faculty^[1,2].

As the main participants of virtual teaching and research communities, teachers' digital literacy directly determines the quality of these communities. The Ministry of Education issued the "Teacher Digital Literacy" framework in 2023, preliminarily dividing teachers' digital literacy into five dimensions: digital awareness, digital technology knowledge and skills, professional development, digital social responsibility, and digital application. In July 2025, the Ministry of Education released the "Digital Empowerment Action for Teacher Development," which explicitly proposes that, through three to five years of effort, "teachers' digital literacy will be comprehensively enhanced, and the proficient

use of digital means in teaching will become the new norm,” while establishing a support system for teacher development empowered by digital and artificial intelligence technologies. Teachers’ digital literacy is a key prerequisite for aligning the Energy and Power Engineering major with the smart energy industry’s demands and cultivating compound innovative talents, and it serves as a strategic fulcrum for realizing an “education–industry–technology” ecological closed loop.

2. The Connotation of Teachers’ Digital Literacy and the Specific Requirements of the Energy and Power Engineering Major

On November 30, 2022, the Ministry of Education issued the industry standard "Teacher Digital Literacy," which defines teachers’ digital literacy as the awareness, ability, and responsibility that enable teachers to appropriately utilize digital technologies to acquire, process, use, manage, and evaluate digital information and resources, identify, analyze, and solve educational and teaching problems, and optimize, innovate, and transform teaching activities. Teachers’ digital literacy represents a deep integration of digital technology, professional competence, and educational mission. It concerns not only “knowing how to use” and “using effectively” the technology, but also “why to use” and “how to use it wisely.” Teachers’ digital literacy requires the ability to transform digital technologies into instructional tools, to fully leverage digital resources to enrich teaching content, and to optimize the process of knowledge dissemination. According to the specific requirements of the Energy and Power Engineering major, teachers must, on the basis of general digital literacy, further integrate engineering practice with digital technologies and convert digital literacy into the capability to solve complex engineering problems. Digital literacy can be deconstructed into five interrelated competency dimensions:

2.1 Technical Application Competence

Teachers’ technical application competence encompasses basic skills in using various digital tools, including proficiency in operating intelligent teaching platforms (such as Rain Classroom and smart classroom systems), utilizing data visualization tools, and mastering intelligent auxiliary tools such as AIGC, GAI, and DeepSeek. In addition, teachers must be proficient in professional digital tools specific to the Energy and Power Engineering field, such as thermodynamic system simulation software (Aspen Plus, Fluent), power plant operation simulation platforms (gas turbine digital simulation software, thermal power plant operation simulation systems), and energy big data analysis tools (refrigeration and air-conditioning analysis software, refrigeration and air-conditioning energy consumption analysis software), in order to enrich teaching methods and expand instructional content.

2.2 Digital Awareness and Instructional Decision-Making Competence

Teachers’ digital awareness and instructional decision-making competence involve understanding the significance of digital technologies in education and actively applying them, as well as leveraging big data capabilities to optimize teaching and enhance instructional decision-making. Teachers utilize learning analytics data (such as from Rain Classroom and smart classroom platforms) to analyze and grasp each student’s learning characteristics and interests, thereby implementing data-driven, “point-to-point” precise instructional interventions. At the same time, teachers are able to dynamically adjust teaching cases based on energy system consumption big data analysis (using tools such as Python and Tableau).

2.3 Integration of Digital Technology and Teaching Competence

Teachers’ competence in integrating digital technology with teaching involves the ability to incorporate digital technologies into instructional design, including reconstructing curriculum systems using knowledge graphs, implementing personalized teaching based on learner profiles, and designing blended learning pathways. In particular, teachers must be able to integrate power plant simulation systems, digital models of energy equipment, and other professional tools into practical teaching to enhance instructional engagement and diversify teaching methods.

For example, in the course "Engineering Thermodynamics," teachers construct a “Energy–Working Fluid–System” knowledge graph and, in combination with student profiles, push personalized learning pathways to achieve progressive deep learning from “thermodynamic laws—cycle analysis—system optimization.” By employing digital twin technology to display the real-time operational status of

thermal systems and using simulation software (such as MATLAB and Fluent) to build three-dimensional visualization models of boiler combustion, teachers enhance students' intuitive understanding of complex energy conversion processes.

2.4 Human–Machine Collaboration and Ethical Decision-Making Competence

Teachers' competence in human–machine collaboration and ethical decision-making involves reconstructing the “teacher–student–machine” tertiary educational ecosystem and transforming the teacher's role, while maintaining clear boundaries between human and machine roles in Energy and Power Engineering instruction. Teachers leverage machines for efficiency in complex thermodynamic calculations and system simulations, while providing guidance in higher-order thinking development, emotional communication, and value formation, highlighting their unique advantages in energy ethics, low-carbon concepts, and advanced analysis of engineering problems. At the same time, teachers uphold the baseline of technological ethics, preventing issues such as algorithmic bias and data privacy breaches.

2.5 Self-Development Competence

In response to the rapid iteration of digital technologies, teachers must establish a continuous learning mechanism, fully leveraging virtual teaching and research community platforms to closely track the frontiers of energy digitalization (such as digital carbon capture technologies and virtual power plant operation models) and to study emerging energy storage technologies, updating their knowledge systems and enriching their knowledge maps through autonomous research and learning.

3. Challenges in Enhancing Digital Literacy of Energy and Power Engineering Teachers

3.1 Insufficient Awareness of Digital Literacy among Teachers

Teachers' insufficient awareness of digital literacy negatively impacts the enhancement of their digital competencies. Some teachers find it difficult to break away from traditional teaching models and lack a clear understanding of the close integration between digitalization and instruction. Their perception and definition of digital literacy often remain limited to the singular perspective of “skills,” without a clear grasp of digital literacy as an educational mindset and attitude, and some hold skeptical or avoidant views toward the empowerment of higher education through digital technologies. Certain teachers believe that fundamental theories such as “thermodynamic laws” do not require digital tools, overlooking the role of digital technologies in simplifying the teaching of complex energy systems, while others continue to use traditional blackboard instruction to teach gas turbine principles without incorporating digital simulations (such as ANSYS flow field modeling) into the curriculum. Data indicate that only 20% of teachers are able to integrate digital technologies into their teaching. Furthermore, the rapid development of digital technologies far exceeds teachers' practical skill advancement, leading to a decline in perceived teaching effectiveness and hindering the development of digital education^[3].

3.2 Misalignment between Training and Professional Needs

Existing training programs lack specificity for the Energy and Power Engineering major. In terms of content, most training is standardized, while specialized topics urgently needed in the Energy and Power field, such as CFD simulation and online carbon emission monitoring, are rarely offered, and training does not differentiate the needs of subfields such as thermal engineering, fluid machinery, or electrical power. In terms of methodology, training primarily takes the form of lectures, lacking “clinical-style practical training” in real scenarios such as virtual power plants, or presenting cases that are detached from authentic contexts like smart power plant operation and maintenance or digital twins of power equipment. In terms of resource provision, national-level resources (such as smart education platforms) are not effectively aligned with school-specific needs, resulting in very low utilization by teachers.

3.3 Insufficient Integration of Professional Teaching and Digital Technology

In the digital intelligence era, Energy and Power Engineering teachers face the dual challenges of

accelerated technological iteration and deepening interdisciplinary integration, yet they generally overlook the spillover effects—such as intelligence, openness, and efficiency—generated by the deep integration of digital technologies with Energy and Power curriculum instruction. Teachers often mechanically transplant online course resources into their teaching and merely use digital teaching platforms to complete routine digital instruction. At the higher-order level of integrated application, many more meaningful, innovative, and practical functions remain underutilized. For instance, teaching platforms such as Chaoxing Fanya and Xuexitong not only provide course content in text, image, audio, and video formats, along with testing and classroom questioning functions, but also enable precise diagnostics of students' performance in practical modules like “Thermal System Design” and “Energy-Saving Technology Applications” through backend data, supporting targeted instructional interventions. The integration of digital technologies with Energy and Power discipline teaching remains superficial, as teachers generally lack the ability to integrate various digital teaching resources (such as cross-institutional power plant simulation resources), reflecting a deeper issue of insufficient alignment between technology application and educational philosophy^[4]. Specifically, this is manifested as follows:

3.3.1 Superficial Application of Technology

Most teachers merely use PowerPoint to replace traditional blackboard instruction and fail to leverage virtual simulations (such as boiler combustion modeling) to visualize high-risk experiments. For example, in the course “Boiler Principles,” very few teachers are able to use 3D models to demonstrate the water circulation system.

3.3.2 Typical Manifestations of Missing Higher-Order Applications

Teachers are only able to demonstrate basic boiler model animations and have not developed interactive experiments for combustion optimization algorithms, reflecting insufficient development of data-driven technologies.

3.3.3 Insufficient Data Analysis Competence

When confronted with real-time data streams from smart power plants, teachers lack the skills to construct predictive maintenance models and demonstrate insufficient capability in data-driven instruction.

3.3.4 Weak Interdisciplinary Integration

The design of new energy systems requires the integration of knowledge such as the Internet of Things and automatic control, yet teachers' limited knowledge structures result in curriculum updates that lag behind industry demands.

4. Strategies for Enhancing Digital Literacy of Energy and Power Engineering Teachers

4.1 Enhancing Awareness: Restructuring Role Positioning

Education in the digital intelligence era exhibits three major characteristics: the methods of knowledge acquisition shift from a single channel to a combination of intelligent recommendation and autonomous retrieval; instructional approaches move from standardized teaching to personalized, data-driven precision education; and knowledge innovation transitions from individual experience accumulation to human-machine collaborative research paradigm innovation. The teaching model evolves from a “teacher–student” binary structure to a “teacher–machine–student” tertiary structure, with teacher-produced instructional content transitioning to intelligent production (automatically generating power plant operation cases under different loads), learning spaces becoming virtually unlimited, and learning processes shifting toward personalization and precision^[5]. Teachers must transform into cultivators of digital intelligence, practitioners of human-machine collaboration, and clearly recognize that digital technologies are not only instructional tools but also conceptual frameworks for reshaping Energy and Power Engineering teaching models. Teachers should boldly experiment with the application of digital technologies in instructional processes, integrating their own digital literacy development with the digital transformation of education, while maintaining a lifelong learning mindset^[6]. In accordance with the requirements of the “Standards for Teacher Intelligent Literacy” and under the impetus of the “Dual-Carbon” strategy, Energy and Power Engineering teachers are redefining their role positioning:

4.1.1 From Knowledge Transmitter to Cultivator of Digital Intelligence

Teachers proactively master tools such as digital twins and AI-based prediction systems, guiding students to use digital tools for energy system optimization and cultivating their capabilities in intelligent energy system operation and maintenance. For example, in the course "Thermal Power Plant," teachers employ digital twin technology to construct a full life-cycle model of the power plant, enabling students to intuitively understand the principles of equipment interconnection.

4.1.2 From Sole Instructor to Practitioner of Human–Machine Collaboration

Teachers position themselves as a collaborative entity of “human intelligence + artificial intelligence,” serving as practitioners of human–machine collaborative education. For example, by integrating virtual power plant experimental platforms into instruction, teachers delegate the explanation of foundational knowledge to AI teaching assistants while focusing on cultivating higher-order thinking skills.

4.1.3 From Technology User to Guardian of Technological Ethics

Teachers strengthen privacy protection in areas such as energy data mining, guide students to explore professional ethical issues including carbon data falsification and algorithmic black boxes, and establish mechanisms for auditing algorithmic bias to prevent the misuse of technology.

4.2 Restructuring Training: Strengthening Personalized Training

Based on the Ministry of Education’s “Teacher Digital Literacy Enhancement Action” and leveraging virtual teaching and research communities, a three-tier resource network is constructed, consisting of the national platform (linked to the “Energy and Power” topic on the National Smart Education Platform), regional centers (connected to the Henan Provincial Continuing Education Public Platform for “Digital Technology” topics), and school-based resources (utilizing “Master Teacher Studios” to implement “clinical-style” training). Considering differences in teachers’ cognitive levels, a progressive, tiered model is adopted—“new teachers → key teachers → discipline leaders”—and a “clinical-style” training approach is applied, which progresses from targeting specific teaching contexts and problems, to proposing solutions, and then implementing them in practice, ensuring that digital literacy training is precise and personalized.

Table 1. Tiered Training Framework for Digital Literacy of Energy and Power Engineering Teachers

Teacher Level	Training Focus for Energy and Power Engineering	Typical Training Programs	Resource Support
New Teachers	Basic Tool Application (operation of smart teaching platforms + use of basic simulation software)	Hands-on Practice with Thermal System Modeling Tools	School-Based Virtual Simulation Platform
Key Teachers	Integration of Technology and Teaching to Develop Digital Twin Courses	Teaching Design for Boiler Combustion AI Optimization and Compressor Fault Diagnosis	Regional Energy Big Data Center
Discipline Leaders	Development of Interdisciplinary Courses (Collaborative Design of Materials–Thermodynamics–Control)	Carbon Footprint Analysis and Dual-Carbon Curriculum Development	National Smart Education Platform

4.3 Innovative Incentive Mechanism: Driving Intrinsic Motivation

Referring to the Ministry of Education’s “Digital Governance Action for Teacher Development” and based on the “Self-Determination Theory,” a three-tiered incentive system—“institutional incentives → developmental incentives → psychological incentives”—is established at the institutional level to satisfy teachers’ needs for autonomy, competence, and belonging, thereby forming a closed-loop mechanism of “evaluation → incentive → development”^[7,8].

4.3.1 Institutional Incentives

Teachers' use of digital instruction is incorporated into performance evaluations, requiring that courses delivered via smart teaching platforms account for no less than 50% of their total teaching load. Leveraging digital teaching platforms (such as Rain Classroom), dynamic digital teacher profiles are established, with assessment elements including the frequency of teacher–student interactions, the quantity of innovative teaching resources, the depth of student learning analytics, and the utilization of online teaching resources. Special funding is allocated to support the development of VR-based safety training systems and other resources, thereby enhancing teachers' motivation for digital instruction.

4.3.2 Developmental Incentives

A tiered “Digital Teaching Competency Certification” system is established, featuring a three-level progressive certification model: “digital tool application → curriculum integration and development → implementation of provincial-level or higher digital teaching projects.” In digital tool application, the workload completed using digital technologies carries increased weight, encouraging teachers to widely apply digital technologies in instructional activities. In curriculum integration and development, outstanding courses are recognized, with priority given for applications to higher-level projects. In the implementation of provincial-level or higher digital teaching projects, the first two responsible personnel of each project receive appropriate funding support and priority in various evaluations compared to other projects of the same level. This system enhances teachers' sense of achievement.

4.3.3 Psychological Incentives

The title of “Master Teacher of Intelligent Energy Education” is established, with appointments issued by the university president; a “Digital Teaching Committee” is formed to participate in institutional digital development decision-making; and, leveraging virtual teaching and research communities, outstanding “digital teaching” cases are promoted to peer institutions. This approach enhances teachers' sense of belonging and professional honor.

Conclusion

Teacher digital literacy serves as the core engine for aligning the Energy and Power Engineering discipline with the “Dual-Carbon” strategy and constructing an intelligent energy education system. By leveraging virtual teaching and research communities to integrate industry, education, and digital intelligence resources, teachers in the Energy and Power Engineering field must proactively embrace the transformation to a “teacher–machine–student” tertiary educational ecosystem under the “Dual-Carbon” strategic context. They need to overcome obstacles in cognitive innovation, targeted training, and multi-dimensional incentives, evolving from technology users into architects of the intelligent energy education ecosystem, ultimately acquiring the capability to cultivate innovative talent in energy and power engineering and support the national energy transition strategy. Future research should deepen the “literacy–practice–evaluation” linkage: on one hand, by building a digital literacy observation database for the Energy and Power Engineering discipline to track the effectiveness of virtual teaching and research community applications; on the other hand, by developing discipline-specific evaluation tools and formulating the “Graded Standards for Digital Competence of Energy and Power Engineering Teachers.” Only by rooting digital literacy in professional educational needs can innovative talent capable of mastering intelligent energy systems be cultivated, ultimately realizing a new paradigm of energy and power education characterized by “ethics as foundation, human–machine collaboration, and student-centered cultivation.”

Funding Project

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