

# The Emergence and Evolution of Vocational College Teachers' AI Application Competency within the TOE Framework: A Dynamic Analysis

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**Abstract:** The factors influencing the emergence of AI application competency among vocational college teachers do not operate in a simple linear fashion. Instead, they interact dynamically to produce outcomes, with antecedents being multiple, concurrent, and intricately interwoven. Based on the Technology - Organization - Environment (TOE) framework, this paper analyzes the pathways of its formation and evolution. The research indicates that the emergence and evolution of vocational college teachers' AI application competency are driven by different factors across the three dimensions of "Technology - Organization - Environment." The initial stage is primarily propelled by environmental pressure, the growth stage is mainly driven by organizational and technological factors, and the mature stage is chiefly characterized by the balanced development of the system. Accordingly, a dynamic evolution model of vocational college teachers' AI application competency is constructed. The conclusions not only enrich the research related to the digital transformation of vocational education but also provide theoretical references and practical pathways for advancing the digital transformation of vocational education through enhancing teachers' digital literacy.

**Keywords:** AI Application Competency; TOE Framework; Vocational Colleges; Teachers; Digitalization

## 1. Introduction

With the Outline for Building an Education Powerhouse (2024-2035) explicitly proposing the in-depth implementation of the national

education digitalization strategy, empowering teacher development with artificial intelligence has emerged as a core issue in the reform of the teaching workforce in the new era. In July 2025, the General Office of the Ministry of Education issued the Notice on Organizing the Implementation of the Action for Digitally Empowering Teacher Development, emphasizing "taking the improvement of teachers' digital literacy as the key, and leveraging the innovative integration and application of digital technology and artificial intelligence technology as the driving force" to systematically advance the enhancement of teachers' digital literacy, the reform of education and teaching, and the transformation of teacher development models. This policy deployment has propelled the empowerment of teacher development by AI from a strategic vision into a new phase of systematic implementation.

In the field of vocational education, the urgency of technological transformation is even more pronounced. In February 2026, the Ministry of Education issued the Opinions on Deepening the Reform of Key Elements in Vocational Education and Teaching (hereinafter referred to as the Opinions). For the first time, it systematically proposed specific requirements such as "refining the teacher competency list" and "strengthening teachers' digital literacy," embedding the enhancement of teacher competency within the framework of linked reforms involving key teaching elements like specialties, curricula, teaching materials, and practical training. The Opinions clearly state the need to "refine and detail teacher competencies based on the new requirements of curriculum and textbook reform, research and develop teacher competency lists, and conduct

evaluations of teacher teaching competencies and specialized training." This implies that the AI application competency of vocational college teachers is no longer an isolated indicator of literacy but a key variable determining the effectiveness of the digital transformation of vocational education, directly impacting the sector's ability to adapt to industrial digital upgrades and serve the development of new quality productive forces. However, the current situation is not optimistic. The Report on the Development of Artificial Intelligence Applications in Vocational Education (2024-2025), led by the School of Education at Tsinghua University, based on an analysis of over 1.4 million valid samples from 32 provinces nationwide, shows that AI application in vocational institutions is overall in its initial stage. At the teacher level, it is "confined to efficiency-enhancing tools, with its effectiveness in teaching still not evident," presenting a superficial characteristic of technology integration. The survey also reveals that while most teachers hold positive expectations for the prospects of AI in education, they commonly face a structural dilemma of "mismatch between technological availability and application capability"—technological tools iterate rapidly, yet teachers' in-depth application skills, teaching transformation abilities, and human-machine collaboration competencies fail to keep pace. This dilemma reflects a deeper issue: the logic behind the emergence and evolutionary path of teachers' AI application competency remains unclear. Competency enhancement still relies on external drives rather than endogenous development, lacking a sustainable mechanism for transitioning from "external support" to "self-generation."

This study focuses on the emergence and evolutionary path of AI application competency among vocational college teachers. Based on the Technology-Organization-Environment (TOE) framework, it systematically identifies the influencing factors of competency emergence and their evolutionary patterns. The research aims to reveal the dynamic evolutionary mechanism through which vocational college teachers' AI application competency transitions from externally driven to endogenously developed, and to construct a three-stage evolutionary model. This provides theoretical support and practical pathways for

teacher professional development in the context of the digital transformation of vocational education.

## **2. Literature Review**

### **2.1 Dimensions and Framework Construction of Vocational College Teachers' AI Application Competency**

Scholars have conducted multi-perspective explorations into the core components of AI application competency among vocational college teachers. The AI Competency Framework for Teachers published by UNESCO proposes adjusting competency dimensions according to educational types. The AI Competency Standards for Vocational Education Teachers, developed by Singapore Polytechnic in collaboration with enterprises, incorporates "industry linkage capability" as a core dimension, forming a three-dimensional framework of "technology application - industry collaboration - ethical norms". The OECD's Trends Shaping Education 2025 report emphasizes that vocational college teachers need the ability to transform AI-assisted training content. Domestic research focuses more on adaptation to specific professional scenarios. Based on the positioning of "dual-qualified" teachers in vocational colleges, Han et al. proposed a three-level competency framework comprising "technology adeptness, industry collaboration, and ethical control," detailing 15 indicators [1]. Xue et al. identified 18 specific competencies across six competency domains (AI thinking, AI ethics, AI fundamentals, AI pedagogy, AI tools, and professional learning about and with AI) and three progressive levels (understanding, applying, and creating) that constitute teachers' AI literacy [2].

### **2.2 Cultivation Pathways and Practice Models for Vocational College Teachers' AI Application Competency**

Both domestic and international research emphasizes that "practice orientation and industry-education collaboration" constitute the core logic for cultivating AI application competency among vocational college teachers, transcending the theoretical limitations of traditional technology training. In Germany's dual vocational education system, teachers enhance their technological transformation and

industry adaptation capabilities by participating in enterprise-based AI virtual simulation projects [3]. Australia's TAFE system, relying on "AI training centers," organizes teachers to collaborate on "problem diagnosis - solution optimization" around AI simulation training in nursing programs, forming a closed loop of competency generation from "industry practice to teaching transformation." Domestic research highlights localized explorations of school-enterprise collaboration. Wang et al. proposed a "school-enterprise collaborative cultivation model," where vocational colleges and AI companies jointly build "AI + specialty" training platforms, enabling teachers to accumulate practical experience through participation in debugging enterprise intelligent detection equipment and developing virtual training software [4]. Hu et al. found that school innovation climate and risk tolerance significantly intervene in the development of teachers' AI acceptance, while policy communication strategies moderate innovation diffusion based on the influence of climate [5]. Diao et al. pointed out the need to strengthen cooperation mechanisms among different stakeholders, improve resource allocation, and balance market-driven and government-led initiatives. They also suggested optimizing policy content, enhancing the synergy of policy instruments, and aligning with both national and international contexts [6].

### **2.3 Analysis of Practical Dilemmas and Influencing Factors in Vocational College Teachers' AI Application**

Currently, empirical research on practical dilemmas has become a research focus, revealing core obstacles and underlying reasons in vocational college teachers' AI application. Internationally, data from the OECD TALIS 2024 survey shows that only 32% of vocational teachers can use AI to capture changes in industrial job competencies, and 61% of teachers believe that "AI tools are incompatible with professional training scenarios." The EU report *Supporting the Digital Transformation of Vocational Education and Training* points out that vocational education teachers generally lack the "secondary development capability of AI tools," making it difficult to adapt to the training needs of certain specialties. Kim identifies factors such as IoT classrooms, systematic curricula, school-based continuous

professional development, theoretical research and practical policies, and fostering a cultural atmosphere of continuous learning and adaptation to AI as important elements influencing teachers' application of AI [7]. Domestic scholars have also conducted detailed research on the dilemmas of vocational teachers' AI application competency. Based on China's TALIS 2024 data, Xu identified a "three-low phenomenon" among vocational college teachers: only 19% have transformed scenarios with AI, 23% can align with industry demands, and 53% are aware of ethical norms [8]. National surveys by Deng et al. indicate that the root of the dilemma lies in the "dual disconnect" of the cultivation system—the disconnect between technology training and vocational training needs, and the disconnect between competency standards and industrial technological changes—resulting in teachers' difficulty in forming an AI application capability that links "teaching-training-industry" [9].

### **2.4 Ethical Norms and Standard System Construction for Vocational College Teachers' AI Application**

Both domestic and international explorations have focused on issues such as data security and algorithmic fairness, indicating that ethics and standards have become crucial supports for competency systems. Internationally, UNESCO's AI Competency Framework for Teachers lists "ethical literacy" as a core dimension, emphasizing that teachers must protect privacy in AI training data collection and student competency assessment. Singapore's AI Competency Standards for Vocational Education Teachers specifically adds a module on "training data security management" to define the boundaries of data use in AI-based skills assessment. Omeh et al. point out that vocational college teachers consistently regard AI technology as an effective educational technology, necessitating the development of ethical principles to ensure that data privacy, integrity, reliability, transparency, and accuracy are not compromised [10]. Domestic research refines ethical requirements in the context of vocational education. Han et al. constructed an "AI Ethical Literacy Framework for Vocational Teachers," proposing indicators such as "data for good governance" and "algorithmic bias avoidance,"

requiring teachers to balance efficiency and fairness in AI-assisted training assessments. The alliance standard Education Large Model+ Overall Reference Framework further specifies that vocational teachers must possess the "ability to review the compliance of AI-generated teaching content" to prevent dissemination biases in industrial cases and technical specifications.

### 3. Theoretical Framework

#### 3.1 The Connotation and Characteristics of Vocational College Teachers' AI Application Competency

The AI application competency of vocational college teachers constitutes a comprehensive competency system within the vocational education field characterized by industry-education integration, wherein teachers integrate AI technology, specialized pedagogical knowledge, and industrial practical experience to optimize teaching processes, innovate training models, and enhance the quality of technical and skilled talent cultivation. Its emergence and evolution are by no means a linear development of a single skill, but rather a complex dynamic process embedded across the entire spectrum of "teaching-training-industry" scenarios, characterized by three distinctive features. First, scenario adaptability: it requires the secondary development or scenario-specific adaptation of AI tools according to the training scenario needs of different specialties, thereby accommodating the particularities of cultivating specialized technical skills. Second, industry-education integration: it enables teachers to capture the dynamic changes in industrial job competency standards through AI technology, transforming real production data and technical specifications into teaching resources and training projects, thus achieving precise alignment between teaching content and industrial demands. Third, ethical sensitivity: in processes such as AI-assisted training data collection and student technical skill assessment, teachers must strike a balance between technological efficacy, data security, and educational equity, upholding the ethical values inherent in vocational education.

#### 3.2 The Applicability and Dimensional Deconstruction of the TOE Analytical

#### Framework

The TOE framework, proposed by Tornatzky and Fleischer in 1990, serves as a classic analytical tool in the field of technology adoption. By integrating three core categories of factors—Technology, Organization, and Environment—it systematically analyzes the logic of technology adoption and development pathways within specific contexts, demonstrating notable systematicity and dynamism.

##### 3.2.1 The technology dimension

The technology dimension focuses on the interaction between the attributes of AI technology and teachers' technological perceptions, serving as the direct support layer for competency emergence. This dimension encompasses both the characteristics of various AI application carriers within vocational training scenarios—where the functional integrity and compatibility with specialized training equipment directly determine the depth and breadth of teachers' technology application—and two key aspects of teachers' technological perceptions: proficiency in using AI tools and accepting AI value. The former constitutes the practical foundation for technology application, while the latter represents the intrinsic motivation driving teachers to actively explore technology integration.

##### 3.2.2 The organization dimension

The organization dimension pertains to the institutional, resource, and cultural conditions within the school, functioning as the meso-level safeguard layer for competency emergence. This dimension is reflected in the school's policy design and resource investment in AI educational applications, which provide institutional space and material foundations for teacher competency development. It also manifests in whether the school fosters a cultural ecosystem that encourages AI teaching innovation—a crucial arena for teacher knowledge sharing and experience iteration. Furthermore, it encompasses incentive and recognition mechanisms, including the acknowledgment of teachers' AI application achievements and tolerance for risks in technological exploration, which constitute the motivational source sustaining teachers' sustained investment in AI application.

##### 3.2.3 The environment dimension

The environment dimension encompasses

external contextual factors such as policies, industry, and society, serving as the external driving layer for competency emergence. This dimension includes the guiding constraints of policies and industry standards, as well as the coercive effects of industrial demands and competitive pressures. As industry requirements for AI capabilities among technical and skilled personnel continue to escalate, these practical pressures stemming from evolving job competency standards compel teachers to proactively adjust the direction and depth of their AI applications to align with actual industrial needs, thereby generating external impetus for competency evolution. Additionally, it involves the inherent constraints of social ethics and public concern, which require teachers to simultaneously embed ethical considerations throughout their AI application competency development process, ensuring that technology application aligns with value principles such as educational equity and data security.

#### **4. Model Construction**

This study constructs a three-stage dynamic evolution model of AI application competence among higher vocational teachers, aiming to reveal its evolutionary pattern from external drive to endogenous development.

##### **4.1 Initial Stage: Environment-Driven Phase**

In the initial stage, the development of teachers' AI application competence primarily relies on external driving forces at the environmental level to achieve its developmental orientation. Specifically, the technological demands arising from industrial upgrading, the institutional pressures formed by educational policies, and the innovation pressures generated by inter-institutional competition collectively constitute the initial impetus for teacher competence development. The characteristic feature of this stage is that teachers exhibit a distinct "reactive" behavioral pattern, with their AI applications mostly concentrated at the operational level of basic tools, without yet forming systematic teaching integration capabilities. From a mechanism perspective, environmental pressures stimulate teachers' preliminary application awareness through a "pressure-response" mechanism, while simultaneously establishing initial linkages with the organizational level through a "buffer-

guidance" mechanism. At this stage, teachers' technological foundations are relatively weak, the organizational support system is not yet fully developed, and competence development demonstrates strong external dependence.

##### **4.2 Growth Stage: Technology-Organization Synergy Phase**

Entering the growth stage signifies that the development of teachers' AI application competence has entered a systematic and standardized track, thereby ensuring its evolutionary synergy and potential. At this stage, AI cognition at the technological level forms a synergistic relationship with institutional support at the organizational level. This is specifically manifested as: teachers transform from passive technology users to active teaching practitioners, beginning to organically integrate AI tools with aspects such as instructional design and implementation; at the institutional level, schools establish comprehensive training systems, resource allocation mechanisms, and incentive policies, providing institutional guarantees for teacher competence development. The key to this stage lies in the "empowerment-catalysis" effect between technological foundations and organizational support: technological capabilities enable teaching innovation, while organizational support creates conditions for technology application, forming a virtuous cycle of mutual reinforcement.

##### **4.3 Mature Stage: System Equilibrium Phase**

The mature stage represents the advanced form of development in teachers' AI application competence. The three dimensions—technology, organization, and environment—achieve deep integration, forming a self-organizing and adaptive developmental ecosystem. This is specifically manifested as: teachers become leaders of educational innovation, capable of creatively utilizing AI technologies based on teaching needs and developing unique application paradigms; at the organizational level, the role shifts from "management" to "empowerment," establishing an institutional environment and cultural atmosphere; environmental pressure transforms from external constraint into an internal development orientation. The core of this stage lies in the dynamic equilibrium among all dimensions: the technological layer consolidates the competence

foundation through a "foundation-construction" mechanism, the organizational layer optimizes the support system through a "synergy-catalysis" mechanism, and the environmental layer clarifies the development direction through a "guidance-pressure" mechanism, ultimately forming a benign interactive pattern of "endogenous generation-exogenous derivation."

### **5. Evolutionary Pathways**

The evolutionary pathway of AI application competence among higher vocational teachers constitutes a process of dynamic coupling among technological, organizational, and environmental dimensions. Its core lies in facilitating the transition of competence from passive adaptation to active innovation through multi-dimensional synergy and differentiated regulation. Based on the three-stage model under the TOE framework, this study proposes the following specific evolutionary pathways:

#### **5.1 Three-Dimensional Interconnectivity: A Sustainable Evolutionary Model**

The enhancement of AI application competence among higher vocational teachers is not the outcome of any single factor but rather the product of the interconnected development of three dimensions: technology, organization, and environment. This three-dimensional interconnectivity constitutes a sustainable evolutionary model, providing a systematic support framework for teacher competence development. The technological dimension, serving as the foundational layer for competence development, requires teachers to continuously elevate their cognitive understanding of AI technology and proficiency in tool application, forming a progressive development trajectory of "technology cognition - tool practice - value identification." The organizational dimension, as the safeguarding layer for competence development, necessitates that institutions construct a multi-tiered support system of "institutional guarantee—resource support—cultural immersion," providing organizational safeguards for teacher competence development through measures such as establishing specialized training mechanisms, allocating intelligent teaching equipment, and fostering an innovative cultural atmosphere. The environmental dimension, functioning as the

guiding layer for competence development, requires educational policymakers to establish a multifaceted driving mechanism of "policy guidance-competition drive-social supervision," forming external synergies to promote teacher competence development by formulating AI education application standards, developing inter-institutional competition evaluation systems, and strengthening social ethical oversight. When advancing AI applications in education, higher vocational institutions should abandon simplistic approaches of technology introduction or institutional reform alone, and instead construct systematically integrated development plans encompassing all three dimensions. By formulating technology capability enhancement programs, improving organizational support policy systems, and responding to external environmental changes, they can achieve sustainable improvement in teachers' AI application competence.

#### **5.2 Synergistic Complexity: Differentiated Organizational Prioritization**

The synergistic development of AI application competence among higher vocational teachers exhibits complexity, with different developmental stages requiring organizations to provide differentiated support strategies. During the environment-driven stage, organizations should focus on establishing "buffer-guidance" mechanisms, alleviating teachers' technological anxiety through foundational training systems and helping teachers understand institutional requirements through policy interpretation workshops. Upon entering the technology - organization synergy stage, organizational support needs to shift toward an "empowerment-catalysis" model, requiring the construction of tiered and categorized training systems, establishment of AI teaching resource centers, and enhancement of incentive mechanisms. The key at this stage is to create conditions for technological capabilities and organizational support to generate synergistic effects. When advancing to the system equilibrium stage, organizational support should be upgraded to an "ecology-empowerment" system: establishing teacher AI competence development portfolios and implementing dynamic diagnosis and precision support. At this stage, particular attention must be paid to avoiding rigidity in organizational support. Differentiated organizational

prioritization can not only match the stage-specific needs of teacher competence development, avoiding resource waste or support deficiencies caused by "one-size-fits-all" support policies, but also drive overall development through stage-specific breakthroughs in key areas, further forming dynamic adjustment mechanisms for support strategies to optimize organizational measures in a timely manner, ultimately achieving synchronous resonance between organizational support and teacher competence development.

### **5.3 Potential Substitutability: High-Level Policy Orientation**

High-level policy orientation plays a crucial role in the development of AI application competence among higher vocational teachers, with its potential substitutability reflected in the deep integration and dynamic guidance of the three dimensions of technology, organization, and environment. Policymakers need to transcend simple technology promotion or institutional constraints, instead constructing forward-looking, systematic, and flexible policy frameworks to stimulate the endogenous momentum of teacher competence development. Specifically, policy orientation should focus on three levels: at the technological level, clarifying stage-specific objectives for teacher technology capability development; at the organizational level, guiding institutions to establish "technology-teaching-management" collaborative innovation mechanisms; at the environmental level, constructing dynamic regulatory mechanisms of "incentive - constraint - feedback," thereby forming a policy ecology characterized by "support for innovation, risk prevention and control, and guidance for development." This high-level policy orientation can not only provide clear directional guidance for teacher competence development but also, through the combined application of policy tools, substitute for certain support conditions that markets or organizations may find difficult to generate spontaneously. Therefore, policymakers need to establish a dynamic evaluation and adjustment mechanism, regularly monitor the effectiveness of policy implementation, and promptly optimize the mix of policy tools. This will ensure that policy orientation continuously aligns with the developmental needs of teachers' competence, thereby maximizing the catalytic effect of

policy substitutability on enhancing teachers' AI application capabilities.

Through multi-case studies based on the TOE framework, this paper analyzes the driving forces at different stages of AI application competence generation among higher vocational teachers and reveals the evolutionary pathways of their AI application competence. However, certain limitations exist in this study. On one hand, although the TOE framework can scientifically examine the driving forces of AI application competence generation among higher vocational teachers from the technological, organizational, and environmental levels, it may not encompass all driving factors. Future research could expand the investigation based on other theoretical perspectives. On the other hand, the difficulties and challenges in developing AI application competence vary among higher vocational teachers of different ages and professional titles. The current research scope is limited to the Zhejiang region; future studies could select cases from multiple regions for in-depth investigation to enhance the generalizability of the conclusions.

### **Acknowledgments**

This work is supported by the 2026 Educational Science Planning Project of Zhejiang Province (Grant No. 2026SCG251), the 2026 Research Project of the Federation of Social Sciences of Zhejiang Province (Grant No. 2026B126), and the 2025 University Visiting Scholar "Teacher Professional Development Project" (Grant No. FX2025095).

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