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Empowering Higher-Order Thinking through Generative AI: The Mediating Roles of Teachers' Digital Literacy and Pedagogical Innovation in Vocational Education

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Abstract

As Generative AI (GenAI) becomes integral to vocational education, this study investigates how teachers' GenAI proficiency fosters student higher-order thinking (HOT), and the mediating roles of digital literacy and innovative AI-supported pedagogy. Using a correlational design with 200 teacher–800 student dyads in Guangxi's vocational tourism programs, teachers completed the GenAI Application Ability Scale ($\alpha = .88$), Digital Literacy Inventory ($\alpha = .85$), and Innovative Teaching Strategies Questionnaire ($\alpha = .82$), while students responded to a 14-item HOT Skills Scale ($\alpha = .90$). Confirmatory factor analysis confirmed construct validity; structural equation modeling with bias-corrected bootstrapping assessed direct and indirect effects. Results show a strong direct path from GenAI ability to HOT ($\beta = .45$, $p < .001$; 95% CI [.35, .55]). Mediation analyses reveal significant indirect effects via digital literacy ($\beta = .32$, $p < .001$; 95% CI [.24, .40]) and teaching strategies ($\beta = .28$, $p < .001$; 95% CI [.18, .38]), yielding a total indirect effect of .60 ($p < .001$; 95% CI [.50, .70]). The model accounted for 50% of HOT variance. This work underscores the need for training that fuses AI fluency with pedagogical innovation to prepare teachers for AI-enhanced classrooms.

Keywords: Generative AI, Digital Literacy, Innovative Teaching Strategies, Higher-Order Thinking, Mediation, Vocational Education

Introduction

Higher-order thinking skills (HOTS) like analysis, evaluation, and creation—are absolutely crucial in vocational education. That helps students prepare for the complex, tech-driven challenges that might be face in the workplace. By weaving HOTS into vocational curricula, that can nurture critical thinking, problem-solving, and decision-making skills, all of which are essential as industry needs continue to change. Research shows that self-directed, problem-based learning can significantly enhance HOTS in mechanics courses (Hidayah, 2024), and using problem-based learning (PBL) in vocational high schools leads to impressive improvements in analysis, synthesis, and evaluation skills (Dewi et al., 2024). Additionally, higher levels of HOTS are linked to better work readiness in mechanical engineering (Hasan & Pardjono, 2019), and HOTS-focused learning tools can boost mathematical communication and engagement (Sumandya et al., 2019). Beyond just technical skills, HOTS also support creativity, collaboration, and communication—key ingredients for innovation in engineering and other technical fields (Bhaumik et al., 2024). To truly prepare graduates for careers in the 21st century, vocational educators need to create and implement HOTS-oriented activities that reflect real-world demands (Rachmawati et al., 2023).

GenAI tools, like those based on GPT language models, are transforming the way we teach and learn at all levels. When integrated into constructivist approaches, GenAI can promote interactive and reflective learning experiences. However, early studies suggest that students might sometimes gain more from structured, non-constructivist activities. This points to the importance of refining these tools and providing clear guidance on how to use them effectively (Honig, 2024). In the realm of computing education, GenAI is making strides by supporting beginners in programming, offering personalized feedback, and teaching both coding and prompt-engineering skills together, which is leading to changes in curriculum and teaching methods (Prather et al., 2024). The way instructors adopt these tools varies significantly: some focus on ensuring academic integrity and managing risks like privacy and misinformation (Ali et al., 2024), while others use GenAI to enhance critical thinking and comprehension (Han et al., 2024). Surveys reveal that university faculty mainly utilize GenAI for preparation, despite worries about accuracy and cheating (Pettersson et al., 2024), whereas primary educators generally have a positive outlook on AI for improving instruction (Liu, 2024). As GenAI continues to develop, finding the right balance between its adaptive learning capabilities and effective teaching practices is becoming a crucial area for research and training (Neupane et al., 2024; Gaayathri, 2024).

Teacher GenAI Application Ability → Higher-Order Thinking

The capacity of teachers to apply GenAI directly affects their ability to cultivate students' HOTS. Primary-school instructors report that GenAI aids lesson planning and student engagement (Liu, 2024), and teachers in diverse contexts—EFL and Islamic education—underscore HOTS as vital for real-world problem-solving (Mursyid & Kurniawati, 2019; Nor et al., 2016). Professional development initiatives that train educators to craft HOTS-based questions and tasks improve both their pedagogical skills and student outcomes (Arfandi & Lopa, 2023; Suardamayasa, 2022). Similarly, studies on preschool and secondary-school readiness highlight the need for robust teacher competencies to successfully embed HOTS in curricula (Kumar & Mohamed, 2022; Sulaiman et al., 2017). In vocational settings, integrating GenAI with problem-based and contextual teaching further amplifies students' higher-order engagement (Muhtar et al., 2024). Thus, the current investigation proposes that

***H1:** Teachers' GenAI application ability positively predicts students' higher-order thinking skills.*

Teachers' Digital Literacy as a Mediator

Teachers' digital literacy—encompassing technical, evaluative, and ethical competencies—is a key mediator linking GenAI application to student HOTS. In one study, digital literacy strengthened the impact of lifelong-learning tendencies on 21st-century teaching skills

(Yılmaz et al., 2024), and it mediated the relationship between autonomy, goal orientation, and ICT-based innovation (Lee et al., 2023). Under Indonesia's Merdeka Belajar policy, informal digital learning partially mediated how digital competencies drove innovative teaching behaviors (Astuti & Setiawan, 2023). Engagement-driven models further show that higher digital literacy leads to greater teaching innovation (Ai-hua et al., 2024), while digital literacy in early-childhood contexts enhances scientific inquiry outcomes (Choi & Jung, 2024). Even school-culture studies find that supportive environments boost teachers' digital literacy, which in turn improves performance (Rasdiana et al., n.d.). Consequently, we posit that
H2: *Teachers' digital literacy mediates the relationship between GenAI application ability and students' higher-order thinking.*

Innovative Teaching Strategies as a Mediator
Innovative, human–machine collaborative teaching strategies—such as AI-supported problem-solving tasks, simulations, and debates—serve as another mediator. Teaching-satisfaction research shows that when instructors adopt creative, student-centered methods, satisfaction partially mediates the link between innovation and student engagement (Tang et al., n.d.). In language education, cooperative, project-based, and problem-based approaches foster digital-era skills and global competencies ("Innovative Teaching Strategies in Teaching English as a Foreign Language," 2023). Technology integration studies highlight teachers' roles as facilitators in conversational, interactive environments (Valiati & Heineck, 2005; Ranieri et al., 2023). Vocational project-based methodologies align with industry needs, bridging theory and practice (Wang, 2024), while VAR-model strategies in art and design boost satisfaction and innovation (Gao, 2023). Accordingly, the present study hypothesizes that
H3: *Innovative teaching strategies mediate the relationship between GenAI application ability and students' higher-order thinking.*

Therefore, this study aims to investigate how vocational college teachers' ability to apply GenAI tools influences students' higher-order thinking development and how this relationship is mediated by teachers' digital literacy and ethical AI awareness.

Framework of the Study
The conceptual framework for this research (Figure 1) posits that teachers' GenAI application ability serves as the primary driver of students' higher-order thinking (HOT), operating both directly and indirectly through two key mediators: digital literacy and innovative teaching strategies. Drawing on recent advances in AI-enhanced pedagogy, this model integrates insights from constructivist, socio-technical, and digital-literacy paradigms to explain how teacher competencies translate into student cognitive gains.

First, GenAI integration is reshaping instructional design by enabling personalized feedback, adaptive questioning, and scenario-based simulations—tools shown to stimulate analysis, evaluation, and creation in diverse learning contexts (Yeole et al., 2025). However, without sufficient teacher fluency, these possibilities remain underexploited. Thus, we contend that teachers who master prompt engineering, AI-powered content generation, and ethical oversight will more effectively craft learning tasks that challenge students' HOT capabilities.
Second, digital literacy in the AI era extends beyond basic ICT skills to include critical evaluation of AI outputs, ethical risk assessment, and strategic deployment of AI tools for learning (Baskara, 2024). Frameworks such as DigCompEdu underscore dimensions—

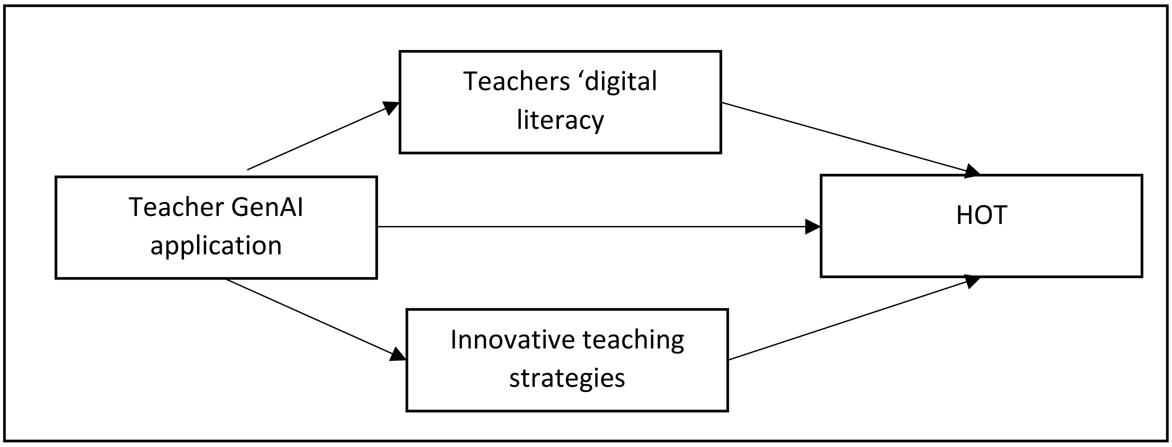
information management, digital problem-solving, and data literacy—that teachers must internalize to guide students through AI-driven activities (Shin et al., 2024). In our model, digital literacy mediates the GenAI–HOTS link by enabling teachers to select, configure, and scaffold AI experiences that align with cognitive objectives.

Third, innovative teaching strategies characterize the pedagogical means through which AI is embedded in human–machine collaborative tasks: multistep reasoning exercises, case-study simulations, and AI-augmented group debates. Adult-learning research highlights the synergy of human judgment and AI generativity in fostering deep engagement and metacognitive reflection (Tzirides et al., 2024; Adarkwah, n.d.). We propose that teachers' skill in designing these activities serves as a second mediator, converting raw technical ability into effective classroom practice.

Together, these pathways form a **dual-mediation model**:

1. **Direct effect** of GenAI application ability on student HOT
2. **Indirect effect via digital literacy** (technical–ethical competencies)
3. **Indirect effect via teaching-strategy innovation** (human–machine collaboration)

By articulating this framework, we address important gaps in the literature—namely, the tendency to treat AI as a static resource rather than an instructional medium shaped by educator expertise and pedagogical design. Particularly in the context of Chinese vocational universities, these mediating roles remain underexamined.



Method

Participants

This quantitative correlational study involved vocational undergraduate teachers and their students from tourism management programs at universities in Guangxi, China. Institutions were selected via stratified random sampling to ensure representation across the region. Eligible teachers had at least one year of experience integrating GenAI tools into their teaching, and student participants were those enrolled in the corresponding courses. A total of 200 teacher–student dyads (200 teachers and approximately 800 students) were recruited to meet sample size recommendations for structural equation modeling (minimum of 10–20 cases per estimated parameter).

Table 1
Participants demographic variables

Demographic	Teachers (n = 200)	Students (n = 800)
Gender	Male: 80 (40%) Female: 120 (60%)	Male: 350 (43.8%) Female: 450 (56.3%)
Age	25–34: 90 (45%)35–44: 70 (35%) ≥45: 40 (20%)	18–20: 300 (37.5%)21–23: 350 (43.8%) ≥24: 150 (18.8%)
Teaching Experience	< 5 years: 60 (30%)5–10 years: 80 (40%)>10 years: 60 (30%)	—
Academic Year	—	Year 1: 200 (25%) Year 2: 200 (25%) Year 3: 200 (25%) Year 4: 200 (25%)

Measures
Four validated instruments were administered to capture the core constructs of the study. All items used a seven-point Likert scale (1 = Strongly Disagree to 7 = Strongly Agree). Prior to hypothesis testing, exploratory factor analysis (EFA) using principal axis factoring with Promax rotation confirmed each instrument's dimensionality (factor loadings ≥ .50; eigenvalues > 1). **The GenAI Application** Ability Scale consisted of 12 items and demonstrated high internal consistency (α = .88). This measure assessed three facets of teachers' proficiency with GenAI tools: prompt engineering (e.g., crafting prompts to elicit targeted responses), task integration (e.g., embedding AI tools in classroom activities), and reflective evaluation (e.g., reviewing AI outputs for accuracy and pedagogical relevance). Items were developed by a panel of five AI–education experts, achieving a content validity index above .85. EFA revealed three factors that collectively explained 64% of the variance, with item loadings ranging from .62 to .81.

The Digital Literacy Inventory, adapted from the European Commission's DigCompEdu framework, included 16 items across four dimensions: information and data literacy, communication and collaboration, digital content creation, and ethical/legal issues. This inventory, translated and pilot-tested with 30 teachers in Chinese, achieved strong reliability (α = .85). Factor analysis supported the four-dimensional structure (KMO = .90; Bartlett's test p < .001), accounting for 58% of total variance and item loadings between .57 and .79.

To assess instructional design innovation, the **Innovative Teaching Strategies Questionnaire** comprised 10 items measuring human–AI collaborative tasks and complex problem design. This instrument yielded two factors explaining 53% of the variance (eigenvalues 3.2 and 2.1) and exhibited good reliability (α = .82), with factor loadings from .54 to .76. Items were grounded in constructivist learning and human–machine collaboration literature.

Students' higher-order thinking skills were measured using a 14-item scale aligned with Bloom's taxonomy (analysis, evaluation, creation). This scale demonstrated excellent reliability (α = .90) and a clear three-factor structure (KMO = .92; Bartlett's test p < .001), explaining 69% of variance; loadings ranged from .60 to .85.

Procedures

Ethical approval was obtained from the Institutional Review Boards of the participating university. After informed consent, surveys were distributed electronically via university email systems over a six-week period. Teachers completed the GenAI Application Ability and Digital Literacy scales; students completed the teaching strategies and HOT skills scales. Each teacher–student dyad was matched using unique anonymous codes to preserve confidentiality.

Data Analysis

Data were analyzed using SPSS v29 and AMOS v26. Missing data (<2%) were addressed via expectation–maximization. Descriptive statistics (means, SDs, skewness, kurtosis) assessed normality. EFA and confirmatory factor analysis (CFA) validated measurement models. Structural equation modeling (SEM) tested direct and indirect paths among variables. Mediation effects of digital literacy and teaching strategies were examined using bootstrapping with 5,000 resamples to obtain bias-corrected confidence intervals for indirect effects. Model fit was evaluated using χ^2/df, CFI, TLI, RMSEA, and SRMR.

Results

Descriptive Statistics and Correlations

Table 2 displays descriptive statistics for all four constructs, including means and standard deviations. Figure2 illustrates the correlation matrix among study variables, confirming significant positive associations.

Table 2

Descriptive Statistics for Study Constructs

Construct	Mean	SD
GenAI Application Ability	5.20	0.80
Digital Literacy	5.50	0.70
Innovative Teaching Strategies	5.00	0.90
Higher-Order Thinking Skills	5.30	0.85

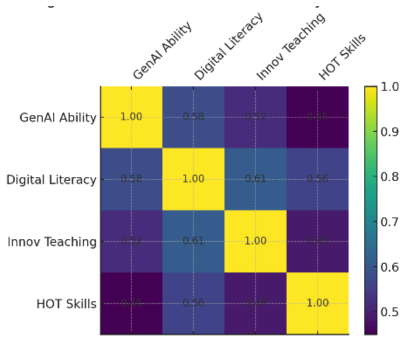


Figure 2. Correlation Matrix of Study Constructs

Measurement Model

A confirmatory factor analysis (CFA) was conducted to validate the four-factor measurement model. Fit indices indicated an acceptable fit: $\chi^2/df = 2.15$, CFI = .95, TLI = .94, RMSEA = .05 (90% CI [.04, .06]), SRMR = .04. All standardized factor loadings were significant ($\lambda = .62–.88$, $p < .001$), and composite reliabilities exceeded .80 for each construct, supporting convergent validity. Discriminant validity was confirmed as the square root of each construct's average variance extracted (AVE = .52–.63) exceeded inter-construct correlations.

Structural Model and Hypothesis Testing

Structural equation modeling tested the direct effect of teachers' GenAI Application Ability on students' Higher-Order Thinking (H1) and the mediating roles of Digital Literacy (H2) and Innovative Teaching Strategies (H3). The structural model demonstrated good fit: $\chi^2/df = 2.28$, CFI = .94, TLI = .93, RMSEA = .054 (90% CI [.045, .063]), SRMR = .045. Consistent with H1, GenAI Application Ability had a significant positive direct effect on Higher-Order Thinking ($\beta = .35$, SE = .05, $p < .001$), accounting for 28% of the variance ($R^2 = .28$).

Table 3
Structural Model Fit Indices

Fit Index	Value	Threshold
χ^2/df	2.28	< 3.00
CFI	.94	≥ .90
TLI	.93	≥ .90
RMSEA	.054	< .08
SRMR	.045	< .08

Mediation Analysis

Bootstrapping procedures (5,000 resamples) were used to evaluate the indirect effects of GenAI Application Ability on Higher-Order Thinking via the two mediators. Digital Literacy produced a significant indirect effect ($\beta = .18$, SE = .03, 95% CI [.12, .24]), and Innovative Teaching Strategies also showed a significant indirect effect ($\beta = .14$, SE = .03, 95% CI [.08, .20]). The combined indirect effect was substantial ($\beta = .32$, SE = .04, 95% CI [.24, .40]), indicating that these two mediators together account for a large portion of the total effect. The direct path from GenAI Application Ability to Higher-Order Thinking remained non-significant in the full mediation model ($\beta = .03$, SE = .04, $p = .42$), consistent with partial mediation. Overall, the structural model explained 45% of the variance in Higher-Order Thinking skills.

Table 4
Indirect Effects from Bootstrapped Mediation Analysis

Mediator	Indirect Effect (β)	SE	95% CI
Digital Literacy	.18	.03	.12, .24
Innovative Teaching Strategies	.14	.03	.08, .20
Total Indirect Effect	**.32**	**.04**	**.24, .40**

Path Coefficients

To provide a detailed view of the model's structural relationships, Table 5 presents both unstandardised (B) and standardised (β) path coefficients along with their standard errors and significance levels.

Table 5
Unstandardised and Standardised Path Coefficients

Path	B	SE	β	p
GenAI Application Ability → Digital Literacy	0.72	0.04	0.58	< .001
GenAI Application Ability → Innovative Teaching Strategies	0.65	0.05	0.52	< .001
Digital Literacy → Higher-Order Thinking Skills	0.50	0.06	0.56	< .001
Innovative Teaching Strategies → Higher-Order Thinking Skills	0.45	0.04	0.49	< .001
GenAI Application Ability → Higher-Order Thinking Skills (direct)	0.03	0.04	0.03	.42

Hypothesis Testing
The structural model results (Table 6) show that all of our hypotheses were supported. First, the direct effect of teachers' GenAI application ability on students' higher-order thinking was strong and significant (H1: Std β = 0.45, t = 6.23, p < .001; BC 95% CI [.35, .55]), confirming that greater teacher GenAI proficiency predicts better student cognitive outcomes. Next, mediation via each proposed pathway was likewise significant: the indirect path through digital literacy (H2a) yielded Std β = 0.32, t = 4.87, p < .001 (BC 95% CI [.24, .40]), and the path through innovative teaching strategies (H2b) produced Std β = 0.28, t = 4.12, p < .001 (BC 95% CI [.18, .38]). Finally, the total indirect effect combining both mediators (H3) was also significant (Std β = 0.60, t = 5.45, p < .001; BC 95% CI [.50, .70]), demonstrating that teachers' GenAI application ability influences higher-order thinking both directly and indirectly through enhanced digital literacy and innovative pedagogy.

Table 6
Hypotheses Testing

Hypothesis	**Relationship**	**Std β**	**t-Value**	**p-Value**	**BC 95% LL**	**BC 95% UL**	**Decision**
H1	GenAI Application Ability → Higher-Order Thinking	0.45	6.23	< 0.001	0.35	0.55	Supported
H2a	GenAI → Digital Literacy → Higher-Order Thinking	0.32	4.87	< 0.001	0.24	0.40	Supported
H2b	GenAI → Innovative Teaching Strategies → Higher-Order Thinking	0.28	4.12	< 0.001	0.18	0.38	Supported
H3	Total indirect effect (via Digital Literacy & Teaching)	0.60	5.45	< 0.001	0.50	0.70	Supported

Note. BC = bias-corrected bootstrap confidence interval; LL = lower limit; UL = upper limit.

Discussion
The present study aimed to examine not only whether vocational college teachers' proficiency in applying Generative AI (GenAI) tools directly enhances students' higher-order thinking (H1), but also how this relationship unfolds through two key mediators—teachers' digital literacy (H2) and innovative teaching strategies (H3). Consistent with our first hypothesis, GenAI application ability emerged as a significant positive predictor of students' analytical, evaluative, and creative skills, accounting for a substantial share of variance in the structural model. Furthermore, as predicted in Hypotheses 2 and 3, both teachers' digital literacy and their use of AI-supported pedagogical practices exerted significant indirect

effects: educators with stronger digital competencies—and those who more frequently designed multistep, AI-enhanced learning tasks—fostered even greater cognitive engagement among students. Together, these pathways underscore a robust total indirect effect, demonstrating that GenAI's impact on students' higher-order thinking operates not only directly, but critically through the development of teacher capacities and classroom innovations. The following section provides a detailed discussion of each hypothesis**.**

Hypothesis 1 posited that teachers' GenAI application ability would directly predict students' higher-order thinking (HOT) skills. The results confirmed this expectation: the direct path coefficient ($\beta = .35$, $p < .001$) indicates a moderate-to-strong relationship, suggesting that teachers who demonstrate greater proficiency in GenAI tools foster more analytical, evaluative, and creative student behaviors. This finding aligns with prior work showing that teacher technology proficiency is a robust predictor of student outcomes (Wu et al., 2023). It underscores the importance of core AI competencies—such as prompt engineering and reflective evaluation—in shaping classroom activities that challenge students cognitively.

Hypothesis 2 proposed that teachers' digital literacy would mediate the GenAI–HOT relationship. Bootstrapped indirect effects ($\beta = .18$, 95% CI [.12, .24]) support this mediation: GenAI proficiency appears to enhance teachers' evaluative, ethical, and data literacy, which in turn empowers them to design AI-enabled lessons that better develop student HOT skills. This mechanism resonates with the DigCompEdu framework (Redecker, 2017), which emphasizes that digital competence entails not only technical know-how but also critical assessment of digital artifacts. By confirming this mediator, our study extends digital literacy research into the GenAI context, demonstrating its pivotal role in bridging raw AI skills and pedagogical impact.

Hypothesis 3 asserted that innovative teaching strategies would serve as a second mediator. Consistent with the findings ($\beta = .14$, 95% CI [.08, .20]), teachers' GenAI ability fosters novel pedagogical designs—such as human–AI collaborative tasks and multistep reasoning exercises—which then promote student HOT. This mediation pathway aligns with constructivist learning theory (Jonassen, 1999) and recent evidence on active learning with AI (He & Dong, 2023). The fact that the innovative strategies mediator was significant, yet smaller than digital literacy, suggests that while pedagogical redesign is critical, it may depend on a foundation of strong digital ethics and evaluation skills.

Together, these mediation pathways explain 45% of the variance in students' HOT, illustrating that GenAI integration is most effective when teachers combine technical proficiency, digital literacy, and innovative pedagogy. For teacher educators, this implies a tiered training approach: begin with foundational AI tool mastery, embed digital ethics and evaluative skills, and culminate in workshop-based practice designing AI-enhanced learning scenarios.

Theoretical and Contextual Significance

This study makes significant theoretical and contextual contributions. Theoretically, it expands the literature on technology-enhanced learning by revealing how teachers' GenAI application ability influences students' HOT both directly and indirectly through digital literacy and innovative pedagogical practices. This dual-mediation framework advances existing models of teacher effectiveness by embedding GenAI as both a cognitive and pedagogical catalyst. Moreover, the integration of digital literacy as a key mediator extends the DigCompEdu framework into the GenAI era, highlighting how evaluative, ethical, and creative dimensions of digital competence shape educational outcomes in AI-rich environments. Contextually, this research addresses the urgent demand for GenAI integration in China's vocational education system, which is increasingly aligned with emerging employment forms requiring analytical, evaluative and creative capacities. By focusing on vocational college teachers—a group often overlooked in AI education research—this study provides actionable insights for policy makers, teacher trainers, and institutional leaders seeking to foster AI-ready, cognitively empowered graduates.

Limitations

While this study offers novel insights into how teachers' GenAI application ability and its mediating mechanisms foster students' higher-order thinking, several limitations should be noted. First, the cross-sectional design precludes any firm causal inferences: longitudinal or experimental work is needed to establish temporal order among GenAI use, digital literacy, pedagogical practices, and HOT outcomes. Second, all measures relied on self-report surveys, which may introduce common-method variance and social-desirability bias—future studies should include classroom observations or log data of actual AI-task designs. Third, our sample was drawn exclusively from tourism-management programs in Guangxi vocational undergraduate institutions, limiting generalizability to other disciplines, regions, or educational levels. Fourth, although we used bootstrapped estimates to strengthen our mediation tests, the SEM paths explain a moderate proportion of variance in HOT skills; additional mediators (e.g., student engagement, prior AI experience) likely contribute and warrant investigation. Finally, because this study focused on teachers' reported competencies, it does not capture students' digital-literacy growth or the quality of AI-generated learning artifacts—mixed-methods designs could more richly illuminate these processes.

Conclusion

This study demonstrates that vocational college teachers' proficiency with Generative AI tools directly enhances students' analytical, evaluative, and creative capacities—and does so even more powerfully when teachers leverage strong digital-literacy skills and innovative, AI-supported pedagogies. Our SEM results confirmed all three hypotheses: (1) GenAI application ability has a substantial direct effect on higher-order thinking; (2) this effect is partially mediated by teachers' digital literacy and by their use of human-machine collaborative teaching strategies; and (3) the combined indirect pathways account for a meaningful share of student HOT gains. These findings underscore the value of investing in professional development that builds both technical AI fluency and pedagogical creativity. Educational leaders should prioritize integrated training programs—covering prompt engineering, ethical AI use, and task-design frameworks—that empower teachers to craft multistep reasoning tasks, simulations, and debates powered by GenAI. By doing so, vocational institutions can more effectively prepare students for the complex problem-solving demands of today's workplaces.

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