

# Generative AI and Higher-Order Thinking in Vocational Education: A Study of Human-Machine Collaboration

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## Abstract

This study dives into how Generative Artificial Intelligence (GenAI) can boost higher-order thinking skills among vocational college students in Guangxi, China. The researchers used a quasi-experimental mixed-methods approach, involving 70 students from information technology and engineering programs. They split the students into two groups: one that experienced GenAI-enhanced interactive teaching and another that followed traditional instruction. The experimental group utilized GenAI in specific roles like “virtual debater” and “decision consultant,” which helped them engage more actively in debates, case analyses, and reflective decision-making. The quantitative results from pre- and post-tests showed a notable improvement in critical thinking, logical reasoning, and reflective skills for the students in the experimental group. Meanwhile, qualitative data gathered from observations, student journals, and interviews highlighted an increase in metacognitive awareness, deeper engagement with problem-solving tasks, and a positive view of AI as a helpful partner in learning. However, there were also concerns about students becoming too reliant on AI tools and the necessity for guided facilitation. The findings indicate that when implemented thoughtfully, GenAI tools can significantly enhance higher-order thinking in vocational education, especially when paired with teaching strategies that promote active learning and reflection. This study underscores the importance of integrating AI ethically and calls for customized instructional designs to ensure fair access and ongoing cognitive growth. These insights add to the ongoing conversation about human-machine collaboration in education and provide valuable guidance for future curriculum innovations in tech-driven learning environments.

**Keywords:** Generative Artificial Intelligence, Higher-Order Thinking, Human-Computer Collaboration, Vocational Colleges and Universities, Teaching Mode Innovation

## Introduction

The emergence of Generative Artificial Intelligence (GenAI) is transforming the education sector by introducing fresh ways to encourage higher-order thinking through engaging, interactive, and collaborative learning experiences. GenAI, in particular, enhances student involvement in critical analysis, reflective reasoning, and problem-solving—essential skills for thriving in today’s complex, tech-driven world (Shaznay, 2025; Singh et al., 2025). By providing personalized and adaptive feedback, and even simulating roles like virtual debaters or decision-making consultants, GenAI creates an environment that nurtures creativity, innovation, and metacognitive growth (Türker & Öztürk, 2025; Owen, 2025). This integration is especially significant in vocational education, where students are not just learning technical skills but also honing the 4C competencies—critical thinking, creativity, collaboration, and communication (Türker & Öztürk, 2025). For students enrolled in information technology and engineering programs at vocational universities in Guangxi, China, the application of GenAI in human-machine collaborative classrooms presents a groundbreaking chance to connect traditional teaching methods with the needs of the digital workforce (Majumdar, 2025).

While the advantages of GenAI are widely recognized, educators and researchers have voiced important concerns about becoming too dependent on AI tools. This overreliance could stifle independent thinking and limit students' ability to think creatively and innovate (Singh et al., 2025; Karagianni, 2024). If we lean too heavily on AI-generated content, we risk producing uniform outputs, shallow engagement, and a lack of emotional richness—elements that could undermine the very skills that vocational education aims to develop (Fischer, 2020). As GenAI becomes more embedded in classrooms, it’s crucial to strike a balance between leveraging technology and nurturing human creativity, ensuring that students remain active participants in their own learning journeys (Airaj, 2024). Moreover, when implementing GenAI, we must address ethical issues like data privacy, algorithmic bias, and equitable access (Christyodetaputri, 2024). These challenges are especially relevant in vocational institutions that cater to students from a variety of educational backgrounds. For example, studies have indicated that students from elite high schools often possess stronger foundational skills—like English proficiency—which can influence their ability to effectively utilize AI tools in higher education (Rongchang, J,2024). This gap underscores the need for customized and inclusive AI strategies that consider different levels of preparedness, so we don’t exacerbate existing educational inequalities.

In light of these concerns, many scholars are championing a blended teaching approach that weaves together generative AI with project-based learning, reflective practices, and collaborative argumentation. This combination aims to boost metacognitive awareness and foster creative expression (Chang, 2025; Rongchang, J,2024). By doing so, students are empowered to critically assess AI-generated content and synthesize knowledge in ways that technology alone simply can't achieve. This not only promotes deep learning but also equips students with the essential skills for independent decision-making and lifelong learning in fast-changing industries. To truly integrate generative AI effectively in vocational classrooms, it requires ongoing collaboration among educators, policymakers, and tech developers to create and refine ethical, pedagogical, and technical frameworks. These frameworks should focus on encouraging critical and creative thinking, ensuring independent learning, and providing equitable access to AI-enhanced education (Airaj, M., 2024; Adarkwah, M. A. , 2024). This study aims to delve into how GenAI can enhance higher-order thinking among

vocational college students in Guangxi, China, through interactive teaching scenarios that involve both humans and machines. Specifically, it will assess how different roles of GenAI—like a “virtual debater” or “decision consultant”—can spark logical reasoning, questioning, and reflection, while also identifying effective teaching strategies that nurture independent, creative thinkers ready to tackle the challenges of the 21st-century workforce.

### **Literature Review**

#### *Higher-Order Thinking in Vocational Education: Definitions and Importance*

Higher-order thinking (HOT) refers to cognitive skills like analysis, evaluation, synthesis, and problem-solving—abilities that are crucial for thriving in today’s complex, real-world situations. In vocational education, where students learn to apply their knowledge in hands-on and technical settings, nurturing HOT becomes even more vital. It not only provides students with the practical skills they need but also empowers them to think critically, adapt to new challenges, and come up with innovative solutions in the workplace (Türker & Öztürk, 2025; Singh et al., 2025). Additionally, higher-order thinking plays a key role in fostering self-regulated learning, where students take charge of their educational journeys by setting goals, tracking their progress, and reflecting on their results. This approach resonates with the ongoing push for reform in vocational education in China, which encourages institutions to move beyond mere rote learning and instead develop adaptable, reflective problem-solvers (Fischer, G,2020).

#### *GenAI in Educational Contexts: Current Uses and Implications*

Generative AI is becoming a game-changer in education, helping to tailor learning experiences, provide smart feedback, and create complex problem-solving scenarios. In the classroom, GenAI acts as a powerful tool that encourages critical thinking through engaging methods like debates, scenario-based learning, and collaborative knowledge-building (Shaznay, 2025; Owen, 2025). The constructivist learning theory backs this up, emphasizing that students thrive when they actively build their own understanding. With GenAI’s knack for delivering instant, personalized feedback and taking on roles like “virtual debater” or “consultant,” learners get valuable chances to dive into critical questioning, logical reasoning, and exploring different perspectives (Singh et al., 2025; Chang, 2025). That said, there are valid concerns about becoming too dependent on AI, which could stifle creativity and lessen engagement with deeper thinking. Some experts warn that without careful teaching strategies, GenAI might unintentionally lead to shallow interactions or uniform results (Singh et al., 2025; Karagianni, 2024).

#### *Human-Machine Collaboration in Learning: Pedagogical Models and Potential*

The concept of human-machine collaboration refers to the synergistic use of AI alongside human cognition to enhance learning. In the classroom, this manifests through scenarios where GenAI participates as a dialogic partner, feedback provider, or content generator. Such models enable learners to test ideas, challenge assumptions, and make decisions based on iterative interaction with the AI system (Airaj, 2024; Adarkwah, 2024).

Studies have shown that AI-assisted collaborative argumentation promotes critical thinking, organizational skills, and motivation. For example, students participating in GenAI-guided debates or design challenges demonstrate improved reflection, reasoning, and engagement with real-world issues (Chang, 2025).

Still, this pedagogical model is not without challenges. Concerns around data privacy, ethical use, and algorithmic bias persist, especially when these tools are implemented in under-resourced or technologically diverse educational contexts (Christyodetaputri, 2024).

### **Teaching Mode Innovation in China's Vocational Colleges**

China's vocational colleges are undergoing rapid reform in response to national strategies emphasizing technological innovation, employment readiness, and educational equity. In regions like Guangxi, where diverse student populations with varying academic backgrounds converge, educators face the challenge of designing inclusive teaching models that harness the power of GenAI while avoiding the risk of widening digital divides (Rongchang, 2024; Majumdar, 2025).

Students from elite high schools tend to perform better when using AI-assisted tools due to stronger foundational skills, such as English proficiency and computer literacy. This disparity necessitates differentiated AI implementation strategies that accommodate learners with different levels of readiness (Rongchang, 2024). At the same time, GenAI tools can support adaptive learning pathways and personalized career guidance, making them powerful assets for innovation in vocational teaching (Majumdar, 2025).

The push for teaching mode innovation also involves blending AI with traditional pedagogies, such as project-based learning and reflective practice, to create equitable and meaningful learning experiences (Fischer, G,2020). These hybrid approaches not only reinforce critical and creative thinking but also mitigate the risk of cognitive dependency on AI tools.

### **Methodology**

#### *Research Design*

This study adopted a quasi-experimental mixed-methods design to investigate the role of Generative Artificial Intelligence (GenAI) in enhancing higher-order thinking among vocational college students. The design combined quantitative pre- and post-tests to measure changes in higher-order thinking skills with qualitative classroom observations and student reflections to understand student experiences and engagement with AI-assisted interactive learning. The approach was selected to capture both the measurable effects and the contextual dynamics of human-machine collaborative teaching.

#### *Research Context and Participants*

The study was conducted at a vocational undergraduate university in the Guangxi region of China, focusing on students enrolled in information technology and engineering programs. These students were chosen due to their academic alignment with AI technologies and their future relevance in AI-integrated workplaces.

A purposive sampling strategy was employed to select two intact classes: one serving as the experimental group (n = approx. 35) and the other as the control group (n = approx. 35). Both groups shared similar demographic profiles, academic levels, and exposure to digital technologies. Only the experimental group was exposed to the GenAI-enhanced interactive teaching intervention. See table 1

Table 1  
*Participant Demographics*

Variable	Category	Experimental Group (N = 35)	Control Group (N = 35)	Total (N = 70)
<b>Gender</b>	Male	22	20	42
	Female	13	15	28
<b>Age</b>	18–20 Years	25	26	51
	21–23 Years	10	9	19
<b>Academic Major</b>	Information Technology	18	17	35
	Engineering	17	18	35
	Other	0	0	0
<b>Prior Ai Experience</b>	Yes	11	9	20
	No	24	26	50
<b>English Proficiency</b>	High	15	13	28
	Moderate/Low	20	22	42

The two groups were balanced in terms of gender, age, academic background, and English proficiency. Most participants had no prior experience with GenAI tools, which provided a uniform baseline for evaluating the intervention's effectiveness.

#### *Intervention Design*

The core of the intervention was a 6-week GenAI-integrated teaching module designed to cultivate higher-order thinking skills—specifically critical thinking, logical reasoning, reflective inquiry, and problem-solving—among vocational college students in information technology and engineering programs. The intervention was implemented in the experimental group only, while the control group followed conventional instructional methods using the same learning content.

#### *Intervention Framework and Structure*

Each week, students participated in one 90-minute GenAI-enhanced session, guided by the following instructional phases:

Table 2

*Structure of Weekly GenAI-Enhanced Instructional Session*

Instructional Phase	Duration	Activities And Focus
<b>Activation Phase</b>	10–15 Minutes	- Instructor Introduces The Weekly Topic And Learning Objectives - Students Receive A Real-World Problem Scenario (E.G., Cybersecurity, System Design)
<b>Exploration Phase</b>	30 Minutes	- Students Interact With Genai Tools In Small Groups - Activities Include Brainstorming, Questioning The Ai, And Evaluating Ai-Generated Outputs - Genai Takes Roles Such As “Virtual Debater” Or “Decision Consultant”
<b>Application Phase</b>	30 Minutes	- Students Collaborate To Complete A Task Or Make Decisions - Examples: Drafting Proposals, Comparing Ai Recommendations, Defending Solutions
<b>Reflection Phase</b>	15–20 Minutes	- Students Respond To Metacognitive Prompts (E.G., Impact Of Ai On Decisions) - Reflections Are Recorded In Journals Or Shared In Group Discussions

*GenAI Tools Used*

- ChatGPT or similar LLM-based platforms were configured with role-based prompts:
  - *Virtual Debater*: Argued for or against student ideas using evidence-based reasoning.
  - *Decision Consultant*: Offered multiple solutions with justifications and asked probing follow-up questions.
  - *Reflective Assistant*: Helped students critique their reasoning process and identify gaps in logic.
- AI tools were accessed through secure platforms using laptops/tablets provided by the university to ensure digital equity.

*Learning Topics Aligned with Curriculum*

The GenAI intervention was embedded in the following thematic areas:

Table 3

*Thematic areas of the GenAI intervention*

Week	Topic Area	Sample Ai Task/Prompt
1	Cybersecurity Ethics	Ai: “Debate Whether Ethical Hacking Should Be Legalized.”
2	System Architecture Design	Ai: “Propose Two System Designs And Justify Each.”
3	Algorithm Bias & Fairness	Ai: “Critique An Algorithm’s Bias And Offer Alternatives.”
4	Ai In Manufacturing	Ai: “Predict Risks Of Automation And Defend A Solution.”
5	Green Technology Engineering	In Ai: “Debate Between Two Sustainable Energy Solutions.”
6	Capstone Simulation	Ai: “Role-Play A Project Manager Reviewing Your Proposal.”

*Instructor and Student Roles*

Table 4 shows the role of instructor and student in the intervention, see table below

Table 4

*Instructor and Student Roles in GenAI-Enhanced Sessions*

Role	Responsibilities
<b>Instructor</b>	<ul style="list-style-type: none"> <li>- Designed Ai Prompts Aligned With Course Objectives</li> <li>- Monitored Genai-Student Interactions And Provided Scaffolding</li> <li>- Facilitated Reflective Discussions</li> <li>- Provided Training In Ai Literacy, Including Critical Evaluation Of Genai Outputs</li> </ul>
<b>Students</b>	<ul style="list-style-type: none"> <li>- Engaged In Collaborative Problem-Solving With Genai As A Thinking Partner</li> <li>- Questioned Ai Outputs, Generated Alternatives, And Justified Decisions Using Evidence</li> <li>- Contributed To Weekly Group Products (E.G., Reports, Debate Summaries, Technical Drafts)</li> </ul>

*Learning Environment*

- Conducted in smart classrooms equipped with Wi-Fi, projection screens, and AI-access devices.
- Students were arranged in teams of 4–5, promoting peer dialogue and accountability.
- All sessions were recorded (audio only) for analysis of interaction quality and engagement, with student consent.

*Instructional Goals of the Intervention*

- Stimulate deep cognitive engagement by confronting students with open-ended problems.
- Enhance students' ability to reason, evaluate evidence, and reflect on their cognitive processes.
- Prepare students for real-world decision-making where AI is a collaborator, not a replacement.

**Instruments***Higher-Order Thinking Skills Scale (HOTSS)*

To assess the development of students' higher-order thinking, a validated Higher-Order Thinking Skills Scale was used. The scale measured key domains such as critical thinking, logical reasoning, reflective thinking, and problem-solving. Pre- and post-tests were administered to both groups.

*Classroom Observation Checklist*

An observation checklist was developed to capture student engagement, collaboration, questioning behavior, and interaction with GenAI tools. Observations were conducted weekly in both groups.

*Student Reflective Journals*

Students in the experimental group were asked to maintain brief reflective journals after each session. Prompts encouraged them to describe how the GenAI tools influenced their thinking and decision-making.

### *Semi-Structured Interviews*

At the end of the module, semi-structured interviews were conducted with 8–10 students from the experimental group. The questions explored students' perceptions of GenAI, its usefulness, and any concerns or challenges faced during the activities.

### *Pilot Study*

Before the main data collection, a pilot study was conducted with a small sample of 10 vocational college students who were not part of the main study groups. The purpose was to assess the clarity, reliability, and contextual relevance of the Higher-Order Thinking Skills Scale (HOTSS). Participants were asked to complete the instrument and provide feedback on item wording, comprehension, and response format. Minor linguistic adjustments were made to better align the items with the students' academic backgrounds and language proficiency. The pilot data were analyzed to determine internal consistency, yielding a Cronbach's alpha of 0.86, indicating good reliability. Based on these results, the instrument was finalized for use in the full study.

### *Data Collection Procedures*

1. Week 0: Pre-test of HOTSS for both groups
2. Weeks 1–6: Intervention sessions and weekly observations
3. Week 6: Post-test of HOTSS, collection of reflective journals, and student interviews

All data were anonymized and collected with informed consent.

### *Data Analysis*

Quantitative data from pre- and post-tests were analyzed using paired sample t-tests and ANCOVA to compare gains between the experimental and control groups.

Observation notes and reflective journals were coded thematically to identify patterns in engagement, reasoning, and collaboration.

Interview transcripts were analyzed using thematic analysis to capture students' experiences, perceived benefits, and limitations of GenAI in promoting higher-order thinking.

### *Validity and Reliability*

To ensure instrument validity, existing validated scales were used where possible. The HOTSS was reviewed by a panel of education and AI experts to ensure relevance to the Chinese vocational context. For reliability, Cronbach's alpha coefficients were calculated, with  $\alpha > 0.80$  considered acceptable.

Triangulation across quantitative and qualitative sources ensured credibility and trustworthiness of findings.

### *Ethical Considerations*

Ethical approval was obtained from the university's research ethics committee. Participants were informed of the study's purpose, their right to withdraw at any time, and the confidentiality of their responses. No personally identifiable data were collected or shared. All tools were used in alignment with current digital ethics and data privacy standards.

## **Results**

This section presents the results of the study examining the impact of GenAI-enhanced interactive teaching on higher-order thinking among vocational college students in Guangxi,

China. Both quantitative and qualitative data were analyzed to assess the extent to which GenAI-supported learning interventions promoted critical thinking, logical reasoning, and reflective inquiry compared to conventional teaching methods.

### Quantitative Findings

#### *Pre-Test and Post-Test Scores*

Data from the Higher-Order Thinking Skills Scale (HOTSS) were collected from both the experimental (n = 35) and control (n = 35) groups before and after the intervention. Descriptive statistics and inferential tests were conducted to compare gains in higher-order thinking.

Table 5

#### *Comparing between Pre-Post Test*

Group	Pre-Test Mean (Sd)	Post-Test Mean (Sd)	Mean Gain	T-Value	P-Value
Experimental	62.4 (8.1)	78.3 (7.2)	+15.9	6.85	<0.001
Control	61.8 (7.9)	66.2 (8.0)	+4.4	2.15	0.037

table 5 shows that students in the experimental group showed a statistically significant improvement in higher-order thinking compared to the control group ( $p < 0.001$ ). The effect size (Cohen's  $d = 1.12$ ) indicates a large effect of the GenAI-integrated intervention.

### Qualitative Findings

To gain deeper insights, thematic analysis was applied to reflective journals, classroom observations, and semi-structured interviews. Three major themes emerged:

#### *Theme 1: AI as a Catalyst for Critical Dialogue*

Students reported that interacting with GenAI in the roles of "virtual debater" and "decision consultant" stimulated questioning behavior, perspective-taking, and evidence-based reasoning:

*"The AI didn't just give answers. It kept asking me 'why,' and I realized I hadn't thought deeply about my decision."* (Student 7)

Classroom observations also noted a higher frequency of open-ended questions and group discussions in the experimental group.

#### *Theme 2: Metacognitive Awareness and Reflection*

Student reflections revealed increased awareness of their own thinking processes:

*"I noticed when I was copying what the AI said without thinking. After a while, I started checking the logic and improving it."* (Student 14)

Instructors also reported that students were more thoughtful in post-session discussions, often referencing their decision-making steps.

#### *Theme 3: Engagement, Motivation, and Challenges*

Students found the GenAI sessions more engaging and motivating compared to traditional lectures:

*"It felt like we were solving real problems, not just memorizing facts."* (Student 21)

However, some expressed concerns about AI bias or unclear prompts, which occasionally disrupted the flow of learning. A few students mentioned needing support in interpreting AI-generated feedback.

### **Integration of Quantitative and Qualitative Results**

The combination of statistically significant gains in HOTSS scores and rich qualitative feedback suggests that GenAI-enhanced learning positively influenced students' higher-order thinking. The findings indicate that role-based AI interaction, when integrated thoughtfully, can scaffold cognitive development and metacognitive reflection.

Therefore, the results demonstrated that GenAI-supported interactive teaching significantly enhanced students' higher-order thinking in vocational education settings. Both quantitative and qualitative data confirm that such integration fosters critical engagement, reflective inquiry, and problem-solving—skills essential for success in 21st-century careers. These findings validate the effectiveness of human-machine collaborative learning as a promising pedagogical model.

### **Discussion and Implications**

This study examined the impact of GenAI-enhanced interactive teaching on the development of higher-order thinking skills among vocational college students in Guangxi, China. Findings indicated that students in the experimental group showed significantly greater improvements in critical thinking, logical reasoning, and reflective inquiry compared to those in the control group. These outcomes demonstrate that integrating GenAI into structured, role-based classroom activities—such as debates, case analyses, and decision-making simulations—can serve as an effective strategy to activate deep cognitive processes and foster metacognitive awareness.

These findings are consistent with research asserting that GenAI can support *constructive friction*—the kind of intellectual challenge that deepens thinking by confronting learners with competing viewpoints and requiring reasoned responses (Owen, 2025; Türker & Öztürk, 2025). When students engage with AI as a “virtual debater” or “decision consultant,” they are nudged to articulate, evaluate, and revise their reasoning—practices central to higher-order thinking. Such interaction aligns with constructivist and dialogic learning theories, which emphasize the value of *cognitive dissonance*, *social negotiation*, and *reflection* as catalysts for deep learning (Vygotsky, 1978; Singh et al., 2025).

The qualitative findings further support this claim. Students reported that GenAI challenged their assumptions, encouraged multi-perspective thinking, and offered immediate feedback that spurred reflection. These outcomes illustrate how AI tools, when well-designed, can serve as *cognitive partners* rather than mere information sources (Chang, 2025). This echoes Dillenbourg's (1999) theory of distributed cognition, where knowledge construction emerges through interaction with both peers and intelligent systems.

Importantly, the effectiveness of GenAI was not purely technological—it depended on pedagogical orchestration. Educators played a crucial role in guiding students to critically evaluate AI-generated content, encouraging *questioning over compliance*, and promoting *reflective discourse*. This aligns with existing scholarship cautioning that unguided AI use may

lead to superficial engagement or overreliance, which risks eroding students' capacity for independent thinking (Karagianni, 2024; Fischer, 2020; Ghapar, 2024).

Nevertheless, limitations must be acknowledged. The sample was limited to a single vocational university and focused on IT and engineering students, potentially limiting generalizability. Furthermore, students had varied levels of prior AI exposure, which may have introduced novelty effects or digital literacy gaps. Finally, the intervention was relatively short-term, and the durability of its effects on higher-order thinking over time remains unknown.

Despite these constraints, the study offers important implications for educational innovation in vocational settings. As Chinese vocational colleges respond to calls for 21st-century skills development, GenAI represents a scalable and engaging tool for cultivating critical and creative thinking—skills often overlooked in skills-based curricula (Adarkwah, M. A. , 2024). However, equitable implementation demands sensitivity to students' backgrounds, including digital readiness, language proficiency, and prior academic experience (Rongchang, J,2024). From a policy standpoint, the findings advocate for the development of ethical, culturally responsive, and pedagogically grounded frameworks for AI integration in education. Institutions must prioritize professional development for teachers, build infrastructure for responsible AI use, and promote collaborative curriculum design that blends AI-enhanced interaction with human guidance (Christyodetaputri, J. H.,2024; Airaj, M., 2024).

## **Conclusion**

This study provides empirical evidence that GenAI, when strategically integrated into interactive teaching practices, can significantly enhance higher-order thinking among vocational college students. The role-based use of GenAI—as a “virtual debater” and “decision consultant”—encouraged learners to engage in critical reasoning, multi-perspective analysis, and reflective inquiry. These outcomes underscore the potential of GenAI not only as a technological tool but as a pedagogical partner that supports metacognitive development.

The findings are particularly relevant for vocational education contexts where practical skills often take precedence over cognitive development. By embedding GenAI into structured, human-machine collaborative learning scenarios, educators can foster critical and creative competencies essential for the 21st-century workforce.

However, the success of such interventions hinges on thoughtful instructional design, ethical implementation, and educator guidance. It also requires sensitivity to learners' digital literacy and educational backgrounds to avoid deepening inequities.

Future research should explore the long-term impact of GenAI on learners' cognitive autonomy and examine its application across diverse disciplines and cultural contexts. Overall, this study contributes to the growing discourse on AI in education and offers practical insights for institutions aiming to innovate teaching while preserving the integrity of human learning.

### Conflict of Interest

The authors have no conflicts of interest to declare.

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### Authors' Contributions

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