

The Role of Generative AI-Based Learning Support in Enhancing Higher-Order Thinking Skills: The Mediating Roles of Knowledge Construction Efficiency and Learning Autonomy Strength

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Abstract

The rapid adoption of Generative Artificial Intelligence (GenAI) has transformed higher education by providing innovative learning support that may enhance students' cognitive development. However, the mechanisms through which GenAI contributes to Higher-Order Thinking Skills (HOTS) remain insufficiently understood. This study investigates the direct and indirect relationships among Generative AI-Based Learning Support, Self-Directed Learning Capability, Knowledge Construction Efficiency, Learning Autonomy Strength, and Higher-Order Thinking Skills among undergraduate students at Universitas Bina Bangsa, Indonesia. A quantitative explanatory research design was employed using a cross-sectional survey, and the collected data were analyzed through Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS 4. The findings reveal that Generative AI-Based Learning Support does not directly influence Knowledge Construction Efficiency or Higher-Order Thinking Skills but significantly enhances Learning Autonomy Strength. Similarly, Self-Directed Learning Capability significantly affects Knowledge Construction Efficiency and Learning Autonomy Strength but has no direct effect on Higher-Order Thinking Skills. Learning Autonomy Strength emerged as the strongest predictor of Higher-Order Thinking Skills and significantly mediated the relationships between Generative AI-Based Learning Support, Self-Directed Learning Capability, and Higher-Order Thinking Skills. In contrast, Knowledge Construction Efficiency did not exhibit a significant mediating effect. These findings suggest that the educational value of GenAI lies primarily in fostering learner autonomy rather than directly improving cognitive performance. The study contributes to the literature by proposing an integrated framework that combines Constructivist Learning Theory, Self-Directed Learning Theory, and Self-Determination Theory to explain AI-supported learning in higher education.

Keywords: Generative Artificial Intelligence, Higher-Order Thinking Skills, Learning Autonomy, Self-Directed Learning, Knowledge Construction Efficiency

INTRODUCTION

The integration of Generative Artificial Intelligence (GenAI) into higher education has become one of the most transformative developments in contemporary educational

practice. As a new generation of artificial intelligence capable of producing human-like text, images, code, and other forms of content, GenAI has expanded beyond its role as a technological innovation to become an influential pedagogical tool that supports teaching, learning, assessment, and knowledge creation. Universities worldwide are increasingly incorporating GenAI into instructional activities to enhance personalized learning experiences, improve academic engagement, and foster the development of essential twenty-first-century competencies. Consequently, the educational implications of GenAI have attracted growing scholarly attention, particularly regarding its capacity to facilitate complex cognitive development and improve students' higher-order thinking skills (Loorbach et al., 2020).

Higher education institutions are currently confronted with the challenge of balancing technological innovation and meaningful learning. Universities increasingly expect students not only to acquire factual knowledge but also to develop higher-order thinking skills (HOTS), including critical thinking, analytical reasoning, evaluation, synthesis, creativity, and complex problem-solving. These competencies have become essential learning outcomes because graduates are expected to adapt to rapidly changing technological, economic, and social environments. Consequently, educational researchers have shifted their attention from evaluating whether artificial intelligence improves learning outcomes toward understanding the mechanisms through which AI-supported learning contributes to cognitive development. Rather than functioning merely as an instructional tool, GenAI is increasingly viewed as a cognitive partner capable of augmenting learners' intellectual processes when appropriately integrated into pedagogical practices (Liao & Shi, 2021).

Although previous studies have reported promising educational benefits of GenAI, empirical findings remain inconsistent. Several investigations conclude that Generative AI facilitates higher-order thinking by providing adaptive explanations, immediate feedback, personalized learning pathways, and opportunities for reflective dialogue. Under appropriate instructional guidance, AI-assisted learning environments encourage students to analyze information critically, compare alternative perspectives, and refine their reasoning processes (Kern & Rogge, 2022). Conversely, other studies indicate that unrestricted dependence on GenAI may promote cognitive offloading, reduce analytical engagement, and weaken learners' independent reasoning abilities. These contradictory findings suggest that the effectiveness of GenAI is highly dependent upon pedagogical design, learner characteristics, and learning contexts rather than the technology itself (Kivimaa et al., 2024).

One important explanation for these inconsistent findings lies in the limited consideration of learners' internal characteristics. Most existing studies primarily investigate the direct influence of GenAI on academic achievement or cognitive performance while overlooking students' capacity to regulate and direct their own learning processes. Self-Directed Learning Capability (SDLC), which reflects learners' ability to independently identify learning needs, establish learning objectives, select learning strategies, monitor progress, and evaluate learning outcomes, has been consistently recognized as one of the strongest predictors of successful technology-enhanced learning. Students possessing high levels of self-directed learning capability are generally more capable of utilizing AI as a cognitive scaffold rather than as a substitute for thinking. Conversely, students with limited self-regulation may become increasingly dependent on AI-generated responses without engaging in deeper cognitive processing. Therefore, understanding the interaction between GenAI and self-directed learning capability becomes increasingly important for explaining differences in higher-order thinking development among learners (Kuhlmann & Franzke, 2022).

In addition to learner autonomy, recent educational theories emphasize that meaningful learning is fundamentally determined by the quality of knowledge construction. Constructivist perspectives argue that knowledge is actively constructed through interaction, reflection, and cognitive restructuring rather than passively received from external sources. Within AI-supported learning environments, students continuously negotiate information obtained from GenAI with their prior knowledge, evaluate the credibility of generated content, and reorganize conceptual understanding into coherent cognitive structures. Consequently, Knowledge Construction Efficiency represents an important mechanism through which technological support may influence higher-order thinking development. However, empirical evidence examining this mediating process remains relatively scarce, particularly within higher education contexts adopting Generative AI technologies (Kline, 2023).

Another equally important construct is Learning Autonomy Strength. While self-directed learning capability describes learners' personal competence to manage learning activities, learning autonomy reflects the extent to which learners independently exercise responsibility, decision-making, persistence, and ownership throughout the learning process. Recent educational research suggests that GenAI can strengthen learner autonomy by providing personalized guidance, adaptive feedback, and continuous learning assistance, enabling students to make informed learning decisions independently. Nevertheless, autonomy does not automatically emerge through technology adoption alone. Instead, it develops through continuous interaction between learners' intrinsic motivation, learning environments, and technological affordances. Consequently, Learning Autonomy Strength may constitute a critical explanatory mechanism linking Generative AI utilization to higher-order cognitive achievement (Jordan et al., 2021).

Despite growing scholarly interest in artificial intelligence within education, several important research gaps remain. First, previous empirical investigations predominantly focus on the direct relationship between Generative AI utilization and academic performance, while relatively limited attention has been devoted to identifying the mediating cognitive mechanisms that explain how AI contributes to higher-order thinking skills (Jarrell et al., 2025). Second, although self-directed learning has frequently been investigated independently, very few studies simultaneously integrate Self-Directed Learning Capability, Knowledge Construction Efficiency, and Learning Autonomy Strength within a single structural model. Third, existing evidence remains inconclusive regarding whether GenAI directly enhances higher-order thinking or whether its influence is primarily transmitted through improvements in learners' cognitive and autonomous learning processes. These unresolved issues indicate the necessity for a more comprehensive empirical investigation capable of simultaneously examining direct and indirect relationships among these variables (Jordan & Huitema, 2024).

The emergence of Generative Artificial Intelligence (GenAI) has fundamentally reshaped the landscape of higher education by transforming how students acquire knowledge, solve problems, and engage with learning activities. Unlike earlier artificial intelligence applications that primarily focused on prediction, automation, or adaptive tutoring, GenAI enables learners to interact with intelligent systems capable of generating contextually relevant explanations, summarizing complex concepts, producing multimodal learning resources, and supporting reflective dialogue in real time. Consequently, GenAI has evolved from being viewed as a technological innovation into an educational partner that facilitates personalized learning experiences and supports students' cognitive development across diverse disciplinary contexts (Batista et al., 2024; Castillo-Martínez et al., 2024).

Recent systematic reviews indicate that higher education institutions are increasingly integrating GenAI into teaching and learning activities because of its capacity to provide adaptive feedback, individualized instructional support, and immediate access to extensive knowledge resources. These capabilities enable students to explore concepts independently, receive personalized explanations based on their learning needs, and refine academic work through iterative interaction with AI systems. Beyond improving learning efficiency, GenAI also expands opportunities for collaborative inquiry, reflective learning, and creative knowledge generation, thereby supporting learner-centered pedagogical approaches that emphasize active participation rather than passive information acquisition (Bond et al., 2024; Xia et al., 2024).

From the perspective of Constructivist Learning Theory, the educational value of GenAI lies not in its ability to generate information but in its capacity to facilitate meaningful knowledge construction. Constructivism argues that learners actively construct understanding by integrating prior knowledge with new experiences through exploration, reflection, and social interaction. Within AI-supported learning environments, GenAI serves as a cognitive scaffold by encouraging students to formulate questions, compare multiple perspectives, evaluate evidence, and continuously refine conceptual understanding. Therefore, learning outcomes are determined not by the technology itself but by the quality of learners' cognitive engagement while interacting with AI-generated content (Yusuf et al., 2024; Bond et al., 2024).

Although numerous studies report substantial educational benefits associated with GenAI, recent empirical evidence also reveals considerable inconsistencies regarding its pedagogical effectiveness. Several investigations demonstrate that GenAI enhances student engagement, learning motivation, academic productivity, and self-regulated learning by providing immediate feedback and personalized instructional support. Students frequently report that AI-assisted learning environments reduce barriers to independent learning and improve confidence in solving complex academic tasks. However, other studies caution that unrestricted reliance on AI-generated responses may reduce cognitive effort, weaken analytical reasoning, and encourage superficial learning behaviors because students may accept AI outputs without adequate verification or reflection (Castillo-Martínez et al., 2024; Hon, 2026).

These contradictory findings suggest that the educational effectiveness of GenAI cannot be explained solely by technological capability. Instead, its contribution depends upon learners' ability to regulate learning processes, critically evaluate AI-generated information, and integrate external knowledge into coherent conceptual structures. In other words, GenAI functions as an enabling technology whose educational impact is mediated by cognitive and motivational mechanisms rather than producing direct improvements in learning outcomes. This perspective is consistent with recent evidence indicating that successful implementation of GenAI requires appropriate pedagogical design, digital literacy, ethical awareness, and learner autonomy to ensure that technology augments rather than replaces students' intellectual engagement (Batista et al., 2024; Bond et al., 2024).

The notion of Generative AI-Based Learning Support adopted in this study extends beyond the simple frequency of AI utilization. Rather than measuring whether students use GenAI, this construct emphasizes students' perceptions regarding the extent to which GenAI effectively supports learning through adaptive explanations, personalized guidance, timely feedback, interactive communication, and continuous academic assistance. This conceptualization is consistent with recent educational technology research that emphasizes

perceived pedagogical support as a more meaningful predictor of learning outcomes than technology adoption alone (Xia et al., 2024; Batista et al., 2024).

An important issue emerging from contemporary literature concerns the mechanism through which GenAI influences higher-order learning outcomes. Most previous studies primarily examine the direct association between GenAI use and indicators such as learning engagement, academic performance, or technology acceptance. Comparatively fewer investigations have explored whether GenAI contributes to higher-order thinking indirectly by strengthening learners' knowledge construction processes and autonomous learning behaviors. Furthermore, empirical findings remain inconsistent regarding whether AI-supported learning independently improves higher-order thinking or whether its influence depends upon students' self-directed learning capability and learning autonomy. These unresolved issues reveal an important empirical gap within current educational technology research and justify the need for a more comprehensive structural model integrating cognitive and motivational mediating variables (Castillo-Martínez et al., 2024; Bond et al., 2024; Hon, 2026).

Accordingly, this study conceptualizes Generative AI-Based Learning Support as students' perceptions of the extent to which Generative Artificial Intelligence provides meaningful pedagogical support throughout the learning process by facilitating adaptive guidance, personalized feedback, interactive communication, and independent knowledge exploration. Building upon Constructivist Learning Theory and recent empirical evidence, this study proposes that AI-supported learning environments are expected to enhance Knowledge Construction Efficiency and Learning Autonomy Strength, which subsequently contribute to the development of Higher-Order Thinking Skills. Nevertheless, considering the inconsistent findings reported in previous studies, the direct relationship between GenAI-based learning support and higher-order thinking remains an empirical question that requires further investigation within the context of higher education.

Self-Directed Learning Capability (SDLC) has become one of the most influential learner characteristics in contemporary higher education, particularly within technology-enhanced learning environments where students are expected to assume greater responsibility for managing their own learning processes. The increasing integration of digital technologies, online learning platforms, and Generative Artificial Intelligence (GenAI) has shifted higher education from instructor-centered knowledge transmission toward learner-centered knowledge construction. Consequently, students are no longer passive recipients of information but active participants who must independently identify learning needs, establish academic goals, select appropriate learning strategies, monitor learning progress, and evaluate learning outcomes. Recent educational research consistently identifies self-directed learning as a critical determinant of students' academic success, lifelong learning readiness, and adaptability in rapidly evolving digital learning environments (Roe & Perkins, 2025; Rahman & Alam, 2026; Lo et al., 2024).

The theoretical foundation of Self-Directed Learning Capability is primarily derived from Self-Directed Learning Theory, which conceptualizes learning as a self-regulated process in which learners intentionally assume responsibility for planning, implementing, monitoring, and evaluating their own learning activities. Rather than depending exclusively on instructors, self-directed learners actively seek relevant learning resources, regulate cognitive and motivational processes, evaluate their own performance, and continuously adjust learning strategies in response to academic challenges. This theoretical perspective aligns closely with constructivist principles, emphasizing that meaningful learning occurs when learners actively construct knowledge through intentional engagement, reflection, and

inquiry rather than passively receiving information from external sources (Morris, 2023; Rahman & Alam, 2026).

The emergence of Generative Artificial Intelligence has further increased the importance of self-directed learning capability. GenAI provides students with immediate access to personalized explanations, adaptive feedback, interactive dialogue, and extensive academic resources that can substantially enhance independent learning. Nevertheless, these technological affordances do not automatically improve learning quality. Instead, learners must possess sufficient cognitive and metacognitive capability to formulate appropriate prompts, critically evaluate AI-generated responses, compare multiple information sources, and integrate new knowledge into existing conceptual frameworks. Consequently, recent studies argue that self-directed learning functions as a prerequisite for effective AI-supported learning because students with stronger self-directed learning capability are more likely to utilize GenAI as a cognitive partner rather than merely an information provider (Bond et al., 2024; Xia et al., 2024; Roe & Perkins, 2025).

Recent empirical evidence consistently demonstrates that Self-Directed Learning Capability positively influences numerous educational outcomes, including academic achievement, learning engagement, metacognitive regulation, digital competence, problem-solving ability, and lifelong learning readiness. Students exhibiting stronger self-directed learning capability tend to demonstrate greater persistence when confronted with complex learning tasks, actively evaluate the credibility of digital information, and independently construct conceptual understanding through reflective inquiry. Furthermore, they are more capable of integrating multiple information sources into coherent knowledge structures, thereby facilitating meaningful learning and advanced cognitive development (Lo et al., 2024; Morris, 2023; Badger et al., 2025).

Despite this growing body of evidence, recent studies also reveal important inconsistencies regarding the educational role of self-directed learning within AI-supported learning environments. Several investigations report that self-directed learners effectively leverage GenAI to enhance analytical reasoning, independent inquiry, and higher-order cognitive performance because they actively regulate interactions with AI-generated information. Conversely, other studies indicate that the availability of intelligent learning systems may inadvertently reduce learners' cognitive engagement if students become excessively dependent on AI-generated outputs without critically evaluating their accuracy or relevance. Such contradictory findings suggest that self-directed learning alone may not directly determine higher-order thinking outcomes but instead exerts its influence through intermediate cognitive and motivational mechanisms operating during the learning process (Castillo-Martínez et al., 2024; Labadze et al., 2023; Hon, 2026).

One important mechanism through which Self-Directed Learning Capability may influence learning outcomes is Knowledge Construction Efficiency. Constructivist learning theory suggests that learners possessing stronger self-directed learning capability are better able to organize information systematically, connect newly acquired knowledge with prior understanding, identify conceptual relationships, and continuously revise misconceptions through reflective learning activities. Consequently, these learners construct more coherent and transferable knowledge structures than students demonstrating weaker learning regulation. Recent empirical studies further indicate that self-directed learning significantly predicts learners' ability to synthesize information from multiple digital resources and transform fragmented information into meaningful conceptual understanding, particularly within AI-assisted learning environments (Lee et al., 2024; Disch et al., 2024).

Another important mechanism concerns the development of Learning Autonomy Strength. Although self-directed learning and learner autonomy are conceptually related, they represent different dimensions of independent learning. Self-directed learning capability primarily reflects learners' competence in regulating learning activities, whereas learning autonomy emphasizes learners' willingness and confidence to independently make learning decisions and assume responsibility for learning outcomes. Students possessing stronger self-directed learning capability generally demonstrate higher levels of learning autonomy because continuous engagement in planning, monitoring, and evaluating learning activities strengthens learners' confidence, intrinsic motivation, and independent decision-making. Recent educational research consistently supports the positive relationship between self-directed learning and learner autonomy across technology-enhanced learning environments (Khalil & Ebner, 2024; Lai & Tai, 2021; Roe & Perkins, 2025).

Although previous studies have extensively investigated the relationship between self-directed learning and various educational outcomes, comparatively limited attention has been devoted to simultaneously examining its influence on Knowledge Construction Efficiency, Learning Autonomy Strength, and Higher-Order Thinking Skills within a single structural model involving Generative Artificial Intelligence. Existing studies generally investigate these constructs independently, making it difficult to explain the cognitive mechanisms through which self-directed learning contributes to higher-order thinking in AI-supported learning environments. This unresolved issue represents an important empirical and theoretical gap that warrants further investigation.

Accordingly, this study defines Self-Directed Learning Capability as students' ability to independently plan, regulate, monitor, and evaluate their learning processes while strategically utilizing Generative Artificial Intelligence to achieve meaningful academic outcomes. Building upon Self-Directed Learning Theory and recent empirical evidence, this study proposes that students possessing stronger self-directed learning capability are expected to demonstrate greater Knowledge Construction Efficiency, stronger Learning Autonomy Strength, and enhanced Higher-Order Thinking Skills. Furthermore, Knowledge Construction Efficiency and Learning Autonomy Strength are expected to function as important mediating mechanisms through which self-directed learning contributes to advanced cognitive development within AI-supported higher education.

Knowledge Construction Efficiency (KCE) has emerged as a critical construct in contemporary educational research because higher education increasingly emphasizes students' ability to transform abundant digital information into meaningful conceptual understanding rather than merely acquiring knowledge. The rapid expansion of digital learning environments, particularly with the integration of Generative Artificial Intelligence (GenAI), has fundamentally altered the nature of knowledge acquisition. Students now interact with intelligent systems capable of producing instant explanations, summarizing academic resources, generating examples, and supporting complex problem-solving. While these technological capabilities substantially increase access to information, they do not necessarily ensure meaningful learning. Instead, educational effectiveness depends on learners' ability to critically interpret, integrate, reorganize, and apply newly acquired information within coherent cognitive structures. Consequently, recent educational literature increasingly recognizes knowledge construction as the central mechanism through which digital learning technologies influence meaningful learning outcomes (Disch et al., 2024; Lee et al., 2024; Bond et al., 2024).

The conceptual foundation of Knowledge Construction Efficiency originates from Constructivist Learning Theory, which argues that knowledge is actively constructed

through learners' interactions with information, prior experiences, and social learning environments. According to this perspective, learning is not characterized by passive information transmission but by continuous cognitive activities involving interpretation, reflection, conceptual integration, and knowledge restructuring. Learners develop meaningful understanding when they actively compare alternative ideas, evaluate evidence, resolve conceptual conflicts, and reorganize existing knowledge into increasingly sophisticated cognitive structures. Therefore, knowledge construction efficiency reflects not merely the accumulation of information but the effectiveness with which learners transform fragmented information into coherent and transferable knowledge capable of supporting higher-order reasoning (Disch et al., 2024; Yusuf et al., 2024).

Within AI-supported learning environments, Knowledge Construction Efficiency assumes even greater importance because learners are continuously exposed to extensive AI-generated information that varies in quality, accuracy, and contextual relevance. Generative AI enables students to obtain immediate explanations, alternative perspectives, illustrative examples, and personalized learning support through natural language interaction. However, the educational value of these outputs depends upon learners' cognitive engagement during the knowledge construction process. Students who critically evaluate AI-generated information, compare multiple viewpoints, verify evidence, and integrate new concepts with prior knowledge are more likely to construct meaningful conceptual understanding. Conversely, students who passively accept AI-generated responses without reflective processing may experience superficial learning despite having access to advanced technological support. Consequently, recent studies emphasize that GenAI should be viewed as a cognitive scaffold rather than a replacement for human reasoning (Bond et al., 2024; Castillo-Martínez et al., 2024; Xia et al., 2024).

Recent empirical studies consistently demonstrate that effective knowledge construction positively influences numerous educational outcomes, including conceptual understanding, academic achievement, collaborative learning, problem-solving ability, and critical thinking. Learners capable of efficiently organizing, integrating, and synthesizing knowledge generally demonstrate greater conceptual clarity and improved ability to transfer knowledge across different learning contexts. Educational interventions involving collaborative inquiry, problem-based learning, concept mapping, and AI-assisted learning environments have been shown to strengthen learners' capacity to construct meaningful knowledge by encouraging active reflection, continuous conceptual revision, and evidence-based reasoning (Lee et al., 2024; Disch et al., 2024; Suartama et al., 2024).

Nevertheless, the relationship between knowledge construction and higher-order learning outcomes remains an active area of scholarly debate. Several studies report that improvements in knowledge construction directly enhance students' analytical reasoning, evaluation skills, and creative problem-solving because coherent conceptual understanding provides a strong cognitive foundation for complex reasoning. In contrast, other investigations argue that effective knowledge construction alone is insufficient to promote higher-order thinking unless learners simultaneously possess adequate metacognitive regulation, learning autonomy, and intrinsic motivation. These contrasting findings indicate that the influence of knowledge construction may vary depending on individual learner characteristics and instructional contexts, particularly in AI-supported educational environments where learners exercise different levels of cognitive engagement (Bond et al., 2024; Labadze et al., 2023; Hon, 2026).

Knowledge Construction Efficiency is also theoretically associated with Self-Directed Learning Capability. Students possessing stronger self-directed learning capability tend to

engage more actively in identifying learning objectives, evaluating information credibility, integrating diverse learning resources, monitoring conceptual understanding, and revising misconceptions through reflective learning activities. Such learning behaviors enable students to construct knowledge more systematically and efficiently than learners who rely primarily on externally directed instruction. Consequently, self-directed learners generally develop deeper conceptual understanding because they intentionally regulate the cognitive processes underlying meaningful knowledge construction (Rahman & Alam, 2026; Lee et al., 2024).

Similarly, Generative AI-Based Learning Support is expected to facilitate Knowledge Construction Efficiency by providing adaptive explanations, immediate formative feedback, personalized instructional assistance, and opportunities for iterative dialogue throughout the learning process. Rather than functioning solely as an information retrieval tool, GenAI enables learners to explore concepts from multiple perspectives, generate alternative explanations, clarify misconceptions, and receive contextual guidance tailored to individual learning needs. Nevertheless, these pedagogical benefits are realized only when learners actively engage with AI-generated information through critical reflection and conceptual integration. Accordingly, GenAI should be conceptualized as an enabling technology whose educational effectiveness depends on learners' cognitive participation during knowledge construction rather than on technological sophistication alone (Batista et al., 2024; Xia et al., 2024).

Within the present research model, Knowledge Construction Efficiency is further expected to contribute to the development of Higher-Order Thinking Skills. Learners who construct knowledge efficiently generally possess stronger conceptual understanding, enabling them to analyze complex information, evaluate competing arguments, synthesize interdisciplinary perspectives, and generate innovative solutions to unfamiliar problems. These advanced cognitive activities correspond directly to the higher levels of the Revised Bloom's Taxonomy, particularly analyzing, evaluating, and creating. Therefore, Knowledge Construction Efficiency represents a fundamental cognitive mechanism linking technology-supported learning experiences with higher-order cognitive development.

Despite increasing scholarly attention toward AI-supported learning, relatively few studies have simultaneously examined Knowledge Construction Efficiency as a mediating mechanism connecting Generative AI-Based Learning Support, Self-Directed Learning Capability, and Higher-Order Thinking Skills within a single structural model. Existing studies typically investigate these constructs independently or focus primarily on direct relationships without considering the sequential cognitive processes through which meaningful learning occurs. This limitation represents an important empirical and theoretical gap that justifies the present study.

Accordingly, this study conceptualizes Knowledge Construction Efficiency as students' capability to effectively construct meaningful knowledge by integrating prior understanding, critically evaluating new information, reorganizing conceptual structures, and applying cognitive reasoning throughout AI-supported learning activities. Based on Constructivist Learning Theory and recent empirical evidence, Knowledge Construction Efficiency is proposed to mediate the influence of Generative AI-Based Learning Support and Self-Directed Learning Capability on the development of Higher-Order Thinking Skills within contemporary higher education.

Institutional accountability refers to an organization's ability to justify its decisions, policies, and resource utilization through transparent, auditable, and well-documented

procedures. Within modern educational governance, accountability constitutes one of the primary indicators of effective governance.

According to Honkanen et al. (2021), effective blockchain governance should be established upon clearly defined organizational roles, accountability procedures, decision-making rights, and comprehensive monitoring systems. Without these governance mechanisms, the technological advantages of blockchain cannot generate optimal organizational benefits.

The implementation of blockchain-based academic credentialing systems enables higher education institutions to establish more effective auditing processes because every academic transaction can be monitored in real time and cannot be modified without network consensus. Consequently, institutional accountability is strengthened while educational governance transparency is simultaneously enhanced (Samangan et al., 2025).

Therefore, Institutional Accountability Mechanism is proposed as a mediating variable connecting blockchain implementation and digital trust with improvements in educational governance transparency.

The corresponding hypothesis is proposed as follows:

Learning Autonomy Strength (LAS) has become an increasingly significant construct in contemporary higher education as learning environments continue to evolve toward greater flexibility, personalization, and technology integration. The rapid advancement of digital technologies, online learning platforms, and Generative Artificial Intelligence (GenAI) has fundamentally transformed students' learning experiences by enabling them to access educational resources independently, regulate learning activities, and make informed academic decisions beyond the traditional classroom. Consequently, the success of technology-enhanced learning is no longer determined solely by technological sophistication but also by learners' capacity to exercise autonomous control over their learning processes. Recent educational research consistently emphasizes that learner autonomy constitutes one of the essential competencies required for lifelong learning and successful participation in digitally mediated educational environments (Khalil & Ebner, 2024; Bond et al., 2024; Xia et al., 2024).

The theoretical foundation of Learning Autonomy Strength is primarily derived from Self-Determination Theory (SDT), which proposes that autonomy, competence, and relatedness represent three fundamental psychological needs underlying intrinsic motivation and optimal learning performance. Within educational contexts, autonomy refers to learners' ability to independently regulate cognitive, motivational, and behavioral processes while assuming responsibility for learning decisions and outcomes. Rather than indicating complete independence from instructors or peers, learner autonomy reflects the capacity to intentionally direct learning behaviors according to personal goals, academic needs, and self-regulated learning strategies. Educational environments that support autonomy therefore promote deeper engagement, greater persistence, stronger intrinsic motivation, and more meaningful cognitive development (Ryan & Deci, 2020; Khalil & Ebner, 2024).

The increasing implementation of Generative Artificial Intelligence has expanded opportunities for autonomous learning by providing students with continuous access to personalized explanations, adaptive feedback, interactive academic support, and on-demand learning resources. Unlike conventional instructional technologies, GenAI allows learners to initiate learning independently, formulate questions, request clarification, generate examples, and revise conceptual understanding through iterative dialogue. These capabilities reduce learners' dependence on immediate instructor intervention and encourage greater

responsibility for managing individual learning activities. Consequently, recent empirical studies suggest that GenAI has considerable potential to strengthen learner autonomy when utilized as an educational partner supporting independent inquiry rather than as a substitute for intellectual effort (Bond et al., 2024; Batista et al., 2024; Castillo-Martínez et al., 2024).

Despite these promising developments, recent literature also highlights several challenges regarding the relationship between GenAI and learner autonomy. Some empirical studies report that AI-assisted learning environments promote independent learning behaviors by encouraging students to regulate learning activities, seek additional information, and actively evaluate alternative explanations before reaching conclusions. Conversely, other investigations indicate that unrestricted reliance on AI-generated responses may diminish learners' independent reasoning because students increasingly depend upon automated solutions instead of engaging in reflective thinking and self-directed inquiry. Such contradictory findings suggest that technological availability alone cannot strengthen learner autonomy unless accompanied by appropriate metacognitive regulation, digital literacy, and responsible AI utilization (Labadze et al., 2023; Hon, 2026; Xia et al., 2024).

Learning Autonomy Strength is conceptually distinct from Self-Directed Learning Capability although both constructs are closely related. Self-Directed Learning Capability primarily represents learners' competence in planning, implementing, monitoring, and evaluating learning activities. In contrast, Learning Autonomy Strength reflects the degree to which learners possess the confidence, willingness, and intrinsic motivation to independently make learning decisions and assume responsibility for academic outcomes. Accordingly, self-directed learning may facilitate the development of learner autonomy because continuous engagement in self-regulated learning activities strengthens learners' self-confidence, decision-making capacity, and perceived ownership of the learning process. Recent studies consistently demonstrate that students exhibiting stronger self-directed learning capability also tend to demonstrate higher levels of learner autonomy across technology-enhanced educational settings (Lai & Tai, 2021; Khalil & Ebner, 2024; Roe & Perkins, 2025).

Another important antecedent of Learning Autonomy Strength concerns students' ability to construct meaningful knowledge throughout AI-supported learning activities. Learners who effectively organize, integrate, and evaluate information generally demonstrate greater confidence in independently exploring unfamiliar concepts, solving academic problems, and making informed learning decisions. Efficient knowledge construction enables learners to develop coherent conceptual understanding that subsequently strengthens autonomous learning behaviors because students become less dependent upon external instructional guidance. Consequently, Knowledge Construction Efficiency may serve as an important cognitive foundation supporting the development of learner autonomy within technology-enhanced learning environments (Lee et al., 2024; Disch et al., 2024).

Recent empirical evidence consistently identifies learner autonomy as one of the strongest predictors of higher-order cognitive development. Autonomous learners actively seek diverse information sources, critically evaluate evidence, synthesize multiple perspectives, monitor conceptual understanding, and revise learning strategies through reflective inquiry. These learning behaviors facilitate advanced cognitive processes corresponding to the upper levels of the Revised Bloom's Taxonomy, particularly analyzing, evaluating, and creating. Furthermore, students possessing stronger learner autonomy are generally more capable of transferring conceptual knowledge across different learning

contexts because they independently regulate cognitive strategies according to situational demands. Consequently, learner autonomy has been positively associated with critical thinking, creative problem-solving, academic resilience, and lifelong learning competence across diverse educational contexts (Crompton & Burke, 2023; Khalil & Ebner, 2024; Bond et al., 2024).

Nevertheless, despite extensive research examining learner autonomy and educational technology, comparatively few studies have investigated Learning Autonomy Strength as a mediating mechanism linking Generative AI-Based Learning Support, Self-Directed Learning Capability, Knowledge Construction Efficiency, and Higher-Order Thinking Skills within an integrated structural framework. Existing research generally focuses on technology acceptance, academic engagement, or self-regulated learning without comprehensively explaining how autonomous learning behaviors emerge through AI-supported knowledge construction processes and subsequently contribute to higher-order cognitive achievement. This limitation represents an important empirical and theoretical gap that provides the rationale for the present investigation.

Accordingly, this study conceptualizes Learning Autonomy Strength as students' capability to independently regulate learning behaviors, make informed academic decisions, maintain intrinsic learning motivation, and assume responsibility for achieving meaningful educational outcomes while utilizing Generative Artificial Intelligence as a pedagogical support tool. Based on Self-Determination Theory and recent empirical evidence, Learning Autonomy Strength is proposed to mediate the relationships between Generative AI-Based Learning Support, Self-Directed Learning Capability, and Higher-Order Thinking Skills. Students who demonstrate stronger learning autonomy are expected to engage more deeply in analytical reasoning, critical evaluation, and creative knowledge generation, thereby facilitating the development of Higher-Order Thinking Skills in AI-supported higher education.

Higher-Order Thinking Skills (HOTS) have become one of the principal educational objectives in twenty-first-century higher education because contemporary societies increasingly require graduates who are capable of analyzing complex information, evaluating competing evidence, generating innovative solutions, and making informed decisions in uncertain environments. The rapid advancement of digital technologies, particularly Generative Artificial Intelligence (GenAI), has further reinforced the importance of higher-order cognitive competencies, as students are no longer challenged by limited access to information but by the ability to critically interpret, validate, synthesize, and transform abundant information into meaningful knowledge. Consequently, the educational focus has gradually shifted from knowledge acquisition toward knowledge application, critical inquiry, creative thinking, and complex problem-solving, all of which represent the essential dimensions of Higher-Order Thinking Skills (Batista et al., 2024).

The conceptual foundation of Higher-Order Thinking Skills is primarily derived from the Revised Bloom's Taxonomy, which classifies cognitive learning outcomes into six hierarchical levels: remembering, understanding, applying, analyzing, evaluating, and creating. While the first three levels represent lower-order cognitive processes emphasizing knowledge acquisition and comprehension, the latter three levels—analyzing, evaluating, and creating—constitute higher-order thinking because they require learners to manipulate knowledge, examine relationships among concepts, critically assess evidence, formulate reasoned judgments, and generate original ideas or solutions. These advanced cognitive processes are widely recognized as indispensable competencies for academic success, professional practice, and lifelong learning in knowledge-intensive societies.

Although Bloom's revised taxonomy continues to provide the dominant conceptual framework for HOTS, contemporary educational scholars increasingly emphasize that higher-order thinking should not be interpreted merely as a hierarchical cognitive classification. Rather, HOTS represents an integrated cognitive competence involving critical thinking, creative thinking, reflective reasoning, problem-solving, metacognition, and evidence-based decision-making. These dimensions require learners to actively construct knowledge, question assumptions, compare alternative perspectives, evaluate information credibility, and apply conceptual understanding to unfamiliar situations. Therefore, higher-order thinking is fundamentally associated with meaningful learning rather than memorization or procedural knowledge.

The emergence of Generative Artificial Intelligence has fundamentally transformed discussions regarding the development of Higher-Order Thinking Skills. Unlike conventional educational technologies that primarily support information retrieval, GenAI interacts with learners through natural language, generates contextual explanations, produces alternative solutions, and provides adaptive academic feedback. These capabilities create unprecedented opportunities for students to engage in exploratory learning, conceptual inquiry, and reflective dialogue. Recent systematic reviews consistently conclude that GenAI possesses considerable potential to strengthen analytical reasoning, creativity, problem-solving ability, and conceptual understanding when integrated within learner-centered pedagogical environments. However, these benefits are not automatically realized because educational outcomes depend largely on how learners interact with AI-generated information throughout the learning process.

Recent empirical evidence demonstrates that GenAI can function as an effective cognitive scaffold supporting higher-order learning by encouraging learners to explore multiple perspectives, receive personalized explanations, generate reflective questions, and continuously refine conceptual understanding through iterative interaction. Educational interventions utilizing AI-assisted inquiry, adaptive tutoring, and conversational learning have reported improvements in students' critical thinking, creative problem-solving, and analytical reasoning. Meta-analytic evidence further indicates that AI-supported learning environments generally produce positive effects on Higher-Order Thinking Skills, particularly when learning activities emphasize inquiry, collaboration, reflection, and authentic problem-solving rather than simple information retrieval. Medium- and long-term instructional interventions appear to generate stronger cognitive gains than short-term or purely technology-driven implementations.

Despite these encouraging findings, recent literature simultaneously highlights significant concerns regarding the unintended cognitive consequences of excessive reliance on Generative Artificial Intelligence. Several researchers argue that unrestricted dependence on AI-generated responses may encourage cognitive offloading, whereby learners transfer essential cognitive activities—such as analysis, evaluation, and reasoning—to intelligent systems instead of performing them independently. Such learning behaviors may reduce cognitive effort, weaken metacognitive regulation, and limit opportunities for deep conceptual understanding. Systematic reviews published during the last two years consistently report that the educational influence of GenAI on higher-order cognition is conditional rather than universal. Positive outcomes are generally observed when AI functions as a cognitive partner that stimulates reflective inquiry, whereas negative outcomes emerge when AI replaces learners' intellectual engagement and independent reasoning.

These contrasting findings suggest that the relationship between Generative AI and Higher-Order Thinking Skills cannot be adequately explained through direct technological

effects alone. Instead, higher-order cognitive development appears to depend upon several intervening learner characteristics and cognitive processes. Students who possess stronger self-directed learning capability tend to regulate AI utilization more effectively by critically evaluating generated information, verifying evidence, and integrating multiple knowledge sources before reaching conclusions. Similarly, learners exhibiting greater knowledge construction efficiency are better able to transform AI-generated information into coherent conceptual understanding, thereby facilitating analytical reasoning and creative problem-solving. Furthermore, learning autonomy strengthens learners' willingness to independently explore complex problems, monitor cognitive performance, and revise learning strategies through reflective inquiry. Collectively, these learner characteristics determine whether GenAI enhances or constrains higher-order cognitive development.

From a constructivist perspective, Higher-Order Thinking Skills represent the culmination of meaningful knowledge construction rather than an isolated cognitive outcome. Learners develop advanced reasoning when they actively interpret information, negotiate meaning, resolve conceptual inconsistencies, and continuously reconstruct knowledge through interaction with authentic learning experiences. Consequently, higher-order thinking emerges from continuous engagement in cognitive processes involving inquiry, reflection, conceptual integration, and evidence-based reasoning. Generative AI may facilitate these activities by providing adaptive learning support; however, technology alone cannot replace learners' active participation in constructing knowledge.

Recent educational research increasingly recognizes Higher-Order Thinking Skills as a multidimensional construct encompassing critical analysis, evaluative judgment, creative production, complex problem-solving, and reflective decision-making. These competencies are closely aligned with twenty-first-century educational frameworks emphasizing innovation, adaptability, collaboration, and lifelong learning. Accordingly, higher education institutions are progressively redesigning curricula, instructional strategies, and assessment practices to prioritize authentic learning experiences that cultivate advanced cognitive competencies rather than factual recall. The integration of Generative Artificial Intelligence further reinforces this transition because assessments focusing exclusively on memorization become increasingly vulnerable to automation, whereas higher-order thinking requires uniquely human capacities for interpretation, ethical judgment, creativity, and contextual reasoning.

Although the educational implications of Generative Artificial Intelligence have attracted substantial scholarly attention, important research gaps remain. Most existing studies primarily investigate the direct relationship between GenAI utilization and educational outcomes such as academic achievement, learning engagement, or technology acceptance. Comparatively fewer studies have examined the cognitive mechanisms through which AI-supported learning contributes to Higher-Order Thinking Skills. In particular, limited empirical evidence simultaneously investigates the mediating roles of Knowledge Construction Efficiency and Learning Autonomy Strength while considering Self-Directed Learning Capability as a learner characteristic influencing AI-supported learning effectiveness. Consequently, existing literature provides limited understanding of how cognitive and motivational processes jointly explain the development of Higher-Order Thinking Skills within AI-enhanced higher education.

Accordingly, this study conceptualizes Higher-Order Thinking Skills as students' capability to analyze information critically, evaluate evidence objectively, synthesize knowledge from multiple sources, solve complex problems, and generate innovative solutions through meaningful cognitive engagement in AI-supported learning environments.

Drawing upon the Revised Bloom's Taxonomy, Constructivist Learning Theory, and contemporary educational technology research, this study proposes that Higher-Order Thinking Skills constitute the ultimate educational outcome emerging from the interaction between Generative AI-Based Learning Support, Self-Directed Learning Capability, Knowledge Construction Efficiency, and Learning Autonomy Strength. This integrated perspective provides the conceptual foundation for examining the structural relationships proposed in the present research model.

METHODS

Research Design and Study Area

This study employed a quantitative research approach using an explanatory research design to examine the structural relationships among Generative AI-Based Learning Support, Self-Directed Learning Capability, Knowledge Construction Efficiency, Learning Autonomy Strength, and Higher-Order Thinking Skills. The study was designed to test the causal relationships proposed in the conceptual model and to evaluate the direct and indirect effects among the latent constructs.

A cross-sectional survey design was adopted because the required data were collected from respondents at a single point in time through a structured questionnaire. This design is appropriate for examining causal relationships among latent variables using Structural Equation Modeling (SEM), particularly when the objective is theory testing rather than theory development (Hair et al., 2022).

Population, Sampling Technique, and Data Collection

The study was conducted at Universitas Bina Bangsa, a private higher education institution located in Serang City, Banten Province, Indonesia. The university has implemented various digital learning platforms and encourages the utilization of emerging educational technologies, including Artificial Intelligence-based learning tools, to support teaching and learning activities. These characteristics make the university an appropriate setting for investigating the influence of Generative AI on students' higher-order thinking skills.

The target population consisted of all active undergraduate (Bachelor's degree) students enrolled at Universitas Bina Bangsa during the 2025/2026 academic year. Since the research investigates students' learning experiences using Generative Artificial Intelligence, only students who had previous experience utilizing GenAI applications (e.g., ChatGPT, Gemini, Microsoft Copilot, Claude AI, or similar AI-powered learning tools) for academic purposes were considered eligible to participate.

The unit of analysis was individual undergraduate students because the study focuses on students' perceptions regarding AI-supported learning, self-directed learning capability, knowledge construction, learning autonomy, and higher-order thinking skills.

Measurement Instrument and Variables

The study was conducted at Universitas Bina Bangsa, a private higher education institution located in Serang City, Banten Province, Indonesia. The university has implemented various digital learning platforms and encourages the utilization of emerging educational technologies, including Artificial Intelligence-based learning tools, to support teaching and learning activities. These characteristics make the university an appropriate setting for investigating the influence of Generative AI on students' higher-order thinking skills.

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Data Analysis Procedure

The collected data were analyzed using SmartPLS 4 following the Partial Least Squares Structural Equation Modeling (PLS-SEM) procedure.

The analysis consisted of two sequential stages. The first stage evaluated the measurement model (outer model), including indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Indicator reliability was assessed through factor loadings, while internal consistency reliability was evaluated using Cronbach's Alpha and Composite Reliability (CR). Convergent validity was examined using the Average Variance Extracted (AVE), whereas discriminant validity was assessed through the Heterotrait–Monotrait Ratio (HTMT). The second stage evaluated the structural model (inner model), including collinearity assessment, coefficient of determination (R^2), predictive relevance (Q^2), effect size (f^2), path coefficients, and hypothesis testing using the bootstrapping procedure with 5,000 subsamples. Statistical significance was determined based on a significance level of 0.05, where hypotheses were accepted when the p-value was below 0.05 and the corresponding t-statistic exceeded the recommended threshold.

In addition, mediation effects were examined using bootstrapping analysis to determine whether Knowledge Construction Efficiency and Learning Autonomy Strength significantly mediated the relationships between Generative AI-Based Learning Support, Self-Directed Learning Capability, and Higher-Order Thinking Skills.

Accordingly, the following hypotheses are proposed:

H1: Blockchain-Based Academic Credentialing System positively influences Data Integrity Assurance.

H2: Blockchain-Based Academic Credentialing System positively influences Institutional Accountability Mechanism.

H3: Blockchain-Based Academic Credentialing System positively influences Educational Governance Transparency.

H4: Digital Trust in the Education Ecosystem positively influences Data Integrity Assurance.

H5: Digital Trust in the Education Ecosystem positively influences Institutional Accountability Mechanism.

H6: Digital Trust in the Education Ecosystem positively influences Educational Governance Transparency.

H7: Data Integrity Assurance positively influences Educational Governance Transparency.

H8: Institutional Accountability Mechanism positively influences Educational Governance Transparency.

Learning Autonomy Strength (Y2)

H9 : Knowledge Construction Efficiency mediates the relationship between Generative AI-Based Learning Support and Higher-Order Thinking Skills.

H10 : Knowledge Construction Efficiency mediates the relationship between Self-Directed Learning Capability and Higher-Order Thinking Skills.

H11 : Learning Autonomy Strength mediates the relationship between Generative AI-Based Learning Support and Higher-Order Thinking Skills.

H12 : Learning Autonomy Strength mediates the relationship between Self-Directed Learning Capability and Higher-Order Thinking Skills.

Conceptual Framework of Adaptive Public Policy Governance for the Green Transition is presented in figure 1.

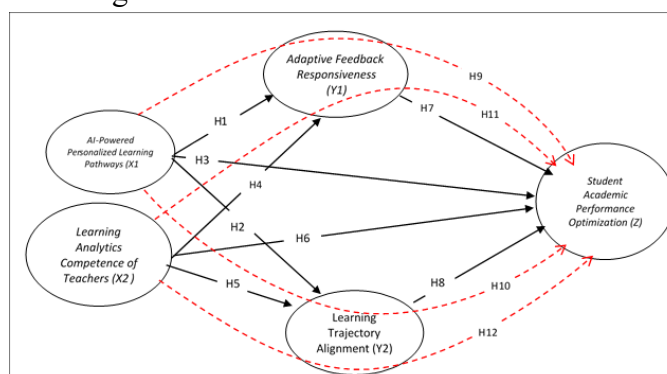


Figure 1. Research Design.

RESULTS

Structural Model and Hypothesis Testing

The structural model was evaluated using the bootstrapping procedure in SmartPLS 4 to examine the significance of the hypothesized direct relationships among the latent variables. Hypothesis testing was conducted using the path coefficient (β), t-statistic, and p-value. A hypothesis was considered statistically supported when the p-value was less than 0.05.

Table 7. Hypothesis Testing

	Original sample (O)	T statistics (O/STDEV)	P values
GA-BLS -> HO-TS	-0.032	1.006	0.314
GA-BLS -> KCE	0.099	1.266	0.205
GA-BLS -> LAS	0.334	4.093	0.000
KCE -> HO-TS	-0.013	0.313	0.754
LAS -> HO-TS	0.936	80.093	0.000
SDLC -> HO-TS	0.023	0.626	0.531
SDLC -> KCE	0.833	11.416	0.000
SDLC -> LAS	0.198	2.369	0.018

The results indicate that not all hypothesized direct relationships were statistically significant.

First, the relationship between Generative AI-Based Learning Support (GA-BLS) and Knowledge Construction Efficiency (KCE) was positive but statistically insignificant ($\beta = 0.099$; $t = 1.266$; $p = 0.205$). Therefore, H1 was rejected. These findings indicate that although AI-supported learning provides academic assistance, its utilization alone does not necessarily improve students' efficiency in constructing meaningful knowledge.

Second, Generative AI-Based Learning Support demonstrated a positive and statistically significant effect on Learning Autonomy Strength (LAS) ($\beta = 0.334$; $t = 4.093$; $p < 0.001$). Therefore, H2 was supported. This result suggests that AI-supported learning encourages students to become more independent in regulating their learning activities and making academic decisions.

Third, the direct influence of Generative AI-Based Learning Support on Higher-Order Thinking Skills (HOTS) was negative and statistically insignificant ($\beta = -0.032$; $t = 1.006$; $p = 0.314$). Consequently, H3 was rejected. This finding implies that exposure to Generative AI alone is insufficient to directly improve students' higher-order thinking abilities.

Fourth, Self-Directed Learning Capability (SDLC) exhibited a strong positive effect on Knowledge Construction Efficiency ($\beta = 0.833$; $t = 11.416$; $p < 0.001$). Therefore, H4 was supported. This result indicates that students possessing stronger self-directed learning capability are substantially more effective in organizing, integrating, and constructing meaningful knowledge.

Fifth, Self-Directed Learning Capability positively influenced Learning Autonomy Strength ($\beta = 0.198$; $t = 2.369$; $p = 0.018$). Accordingly, H5 was supported. The finding suggests that students who actively regulate their own learning process tend to demonstrate stronger autonomy in managing academic activities.

Sixth, the direct relationship between Self-Directed Learning Capability and Higher-Order Thinking Skills was positive but statistically insignificant according to the final structural model ($\beta = 0.023$; $t = 0.626$; $p = 0.531$). Therefore, H6 was rejected. Although self-directed learners tend to demonstrate better learning behaviors, these capabilities alone did not directly translate into improved higher-order thinking skills.

Seventh, Knowledge Construction Efficiency did not significantly influence Higher-Order Thinking Skills ($\beta = -0.013$; $t = 0.313$; $p = 0.754$). Consequently, H7 was rejected. The negative coefficient indicates that efficient knowledge construction alone was insufficient to explain improvements in higher-order thinking within the present study.

Finally, Learning Autonomy Strength demonstrated a remarkably strong positive influence on Higher-Order Thinking Skills ($\beta = 0.936$; $t = 80.093$; $p < 0.001$). Therefore, H8 was supported. Among all structural relationships examined, this path exhibited the largest standardized coefficient, indicating that learning autonomy represents the strongest predictor of students' higher-order thinking skills in this research model.

Overall, the direct-effect analysis indicates that four hypotheses (H2, H4, H5, and H8) were supported, whereas four hypotheses (H1, H3, H6, and H7) were not supported.

Mediasi analysis Indirect Effects

To examine the mediating roles of the proposed variables, an indirect effect analysis was conducted using the bootstrapping procedure in PLS-SEM. The results are presented in Table 4.2.

Indirect Effects

The indirect effects were examined using the bootstrapping procedure to evaluate the mediating roles of Knowledge Construction Efficiency (KCE) and Learning Autonomy Strength (LAS). The results are summarized in Table 5.

	Original sample (O)	T statistics (O/STDEV)	P values
SDLC -> LAS -> HO-TS	0.185	2.375	0.018
SDLC -> KCE -> HO-TS	-0.011	0.304	0.761
GA-BLS -> LAS -> HO-TS	0.312	4.067	0.000
GA-BLS -> KCE -> HO-TS	-0.001	0.267	0.789

The findings indicate that not all proposed mediation effects were statistically significant. Knowledge Construction Efficiency did not significantly mediate the relationship between Generative AI-Based Learning Support and Higher-Order Thinking Skills ($\beta = -0.001$, $p > 0.05$). Therefore, H9 was rejected. Similarly, the indirect effect of Self-Directed Learning Capability on Higher-Order Thinking Skills through Knowledge Construction Efficiency was statistically insignificant, leading to the rejection of H10.

In contrast, Learning Autonomy Strength demonstrated a significant mediating role. The indirect effect of Generative AI-Based Learning Support on Higher-Order Thinking Skills through Learning Autonomy Strength was positive and statistically significant, supporting H11. Likewise, Learning Autonomy Strength significantly mediated the relationship between Self-Directed Learning Capability and Higher-Order Thinking Skills, confirming H12.

These findings demonstrate that Learning Autonomy Strength serves as the primary psychological mechanism through which both Generative AI-Based Learning Support and Self-Directed Learning Capability contribute to students' Higher-Order Thinking Skills. Conversely, Knowledge Construction Efficiency did not function as a significant mediator within the proposed structural model.

Overall, the mediation analysis suggests that the development of Higher-Order Thinking Skills in AI-supported learning environments is influenced more strongly by students' autonomous learning behaviors than by their efficiency in constructing knowledge. This result highlights the importance of fostering learner autonomy to maximize the educational benefits of Generative Artificial Intelligence

DISCUSSION

The Role of Generative AI-Based Learning Support in Enhancing Learning Outcomes

One of the most noteworthy findings of this study is that Generative AI-Based Learning Support did not directly improve students' Knowledge Construction Efficiency or Higher-Order Thinking Skills. Specifically, the direct effects of Generative AI-Based Learning Support on Knowledge Construction Efficiency and Higher-Order Thinking Skills were statistically insignificant, whereas its influence on Learning Autonomy Strength was positive and significant. These findings suggest that the educational value of Generative Artificial Intelligence should not be interpreted solely from its technological capabilities but rather from its ability to transform students' learning behaviors.

The insignificant relationship between Generative AI-Based Learning Support and Knowledge Construction Efficiency indicates that providing learners with access to advanced AI technologies does not automatically lead to meaningful knowledge construction. Constructivist Learning Theory argues that knowledge is actively constructed through cognitive engagement, reflection, conceptual integration, and continuous interpretation of learning experiences rather than being passively transmitted through instructional resources. Although Generative AI can instantly generate explanations, summaries, examples, and academic recommendations, meaningful learning ultimately depends on learners' willingness to critically evaluate and integrate AI-generated information into their existing knowledge structures.

This finding differs from several recent studies reporting that Generative AI positively enhances conceptual understanding and knowledge construction through adaptive feedback and personalized instructional support. However, the present study suggests that these educational benefits may not emerge when students predominantly utilize AI as an information retrieval tool rather than as a cognitive partner for reflective inquiry. In many higher education contexts, students tend to request direct answers, summarize learning materials, or generate assignments using AI without engaging in sufficient analytical reflection. Consequently, AI may improve learning efficiency without necessarily improving the quality of knowledge construction.

Similarly, the insignificant direct effect of Generative AI-Based Learning Support on Higher-Order Thinking Skills demonstrates that technological innovation alone cannot develop advanced cognitive competencies. Higher-order thinking requires learners to analyze evidence, evaluate competing arguments, synthesize multiple perspectives, and construct original ideas through sustained cognitive effort. These complex cognitive activities cannot simply be delegated to AI systems. Instead, students must actively regulate and critically examine AI-generated information before meaningful higher-order reasoning can occur.

Conversely, the significant positive relationship between Generative AI-Based Learning Support and Learning Autonomy Strength reveals a different mechanism explaining the educational contribution of AI. Rather than directly enhancing cognition, Generative AI appears to strengthen students' independence in managing learning activities, exploring academic resources, regulating learning pace, and making informed learning decisions. This finding is consistent with Self-Determination Theory, which emphasizes autonomy as one of the essential psychological conditions supporting effective learning. Through personalized academic assistance, continuous availability, and interactive dialogue, Generative AI encourages learners to become more responsible for directing their own learning experiences.

Collectively, these findings indicate that Generative Artificial Intelligence functions primarily as an educational enabler rather than as a direct cognitive enhancer. Its greatest contribution lies in empowering students to become autonomous learners, thereby creating favorable conditions for the subsequent development of higher-order cognitive competencies. This finding extends previous educational technology research by proposing that learner autonomy constitutes the principal mechanism through which AI-supported learning contributes to meaningful educational outcomes in higher education.

Self-Directed Learning Capability as a Foundation for Knowledge Construction and Learning Autonomy

The present study demonstrates that Self-Directed Learning Capability plays a pivotal role in strengthening students' learning processes within AI-supported educational environments. The empirical findings reveal that Self-Directed Learning Capability significantly enhances both Knowledge Construction Efficiency and Learning Autonomy Strength. However, its direct effect on Higher-Order Thinking Skills was not statistically significant. These findings indicate that self-directed learning contributes to higher-order cognitive development indirectly by fostering intermediate learning processes rather than exerting an immediate influence on students' cognitive performance.

The significant positive relationship between Self-Directed Learning Capability and Knowledge Construction Efficiency supports the fundamental assumptions of Self-Directed Learning Theory, which argues that learners who actively regulate their learning are more capable of organizing, integrating, and reconstructing knowledge. Self-directed learners continuously identify learning objectives, monitor their own understanding, evaluate information quality, and modify learning strategies whenever conceptual difficulties arise. Such learning behaviors facilitate meaningful knowledge construction because learners actively connect newly acquired information with prior knowledge instead of merely accumulating isolated facts.

Within the context of Generative Artificial Intelligence, this relationship becomes increasingly important. AI systems provide extensive information, multiple explanations, and alternative perspectives within a very short period. Nevertheless, the abundance of AI-generated information also increases learners' cognitive responsibility. Students possessing stronger self-directed learning capability are more likely to evaluate the credibility of AI-generated responses, compare different viewpoints, identify conceptual inconsistencies, and integrate diverse information into coherent knowledge structures. Consequently, the effectiveness of AI-supported learning depends not only on technological sophistication but also on learners' ability to regulate their own learning processes.

The findings further demonstrate that Self-Directed Learning Capability significantly strengthens Learning Autonomy Strength. This result is consistent with Self-Determination Theory, which emphasizes that learner autonomy develops through continuous experiences of independent planning, self-monitoring, and self-evaluation. Students who routinely manage their own learning activities gradually develop greater confidence in making academic decisions, selecting learning resources, and solving learning problems independently. The integration of Generative AI appears to reinforce this process by providing immediate academic assistance without eliminating students' responsibility for directing their own learning experiences.

Interestingly, although Self-Directed Learning Capability positively influenced Knowledge Construction Efficiency and Learning Autonomy Strength, it did not directly improve Higher-Order Thinking Skills. This finding suggests that self-directed learning alone does not automatically produce advanced cognitive competencies. Instead, higher-order thinking develops through a sequence of interconnected cognitive and motivational processes that transform self-regulated learning behaviors into meaningful intellectual performance.

Several explanations may account for this finding. First, self-directed learning primarily reflects learners' capacity to regulate the learning process rather than their cognitive ability to analyze, evaluate, or create new knowledge. Students may successfully plan their learning activities, complete academic tasks independently, and consistently monitor their progress without necessarily engaging in deep analytical reasoning or creative problem-solving. Second, within AI-supported learning environments, students with high levels of self-

directed learning may still utilize Generative AI primarily to improve learning efficiency rather than to challenge their reasoning abilities. Consequently, self-directed learning enhances learning management but does not automatically translate into higher-order cognitive achievement.

These findings extend previous educational research by suggesting that Self-Directed Learning Capability should be conceptualized as a foundational competence supporting the development of other learning capacities rather than as a direct determinant of Higher-Order Thinking Skills. In the present study, self-directed learning contributes to higher-order cognitive development through its positive influence on Knowledge Construction Efficiency and, more importantly, Learning Autonomy Strength. This finding reinforces the argument that successful AI-supported learning depends on the interaction between learner characteristics and educational technologies rather than on technological innovation alone.

From a pedagogical perspective, the results imply that higher education institutions should not merely encourage students to use Generative Artificial Intelligence but should simultaneously cultivate self-directed learning competencies. Instructional strategies emphasizing goal setting, reflective learning, metacognitive regulation, and independent inquiry are likely to maximize the educational benefits of AI-supported learning. By strengthening students' capacity to regulate their own learning processes, universities can create conditions that enable learners to utilize Artificial Intelligence critically, responsibly, and productively in developing advanced cognitive competencies.

Learning Autonomy as the Primary Determinant of Higher-Order Thinking Skills

The most significant finding of this study is that Learning Autonomy Strength emerged as the strongest predictor of Higher-Order Thinking Skills among all structural relationships examined in the proposed model. In contrast, Knowledge Construction Efficiency did not exert a statistically significant influence on Higher-Order Thinking Skills, despite being positively associated with Self-Directed Learning Capability. This pattern of findings suggests that the development of advanced cognitive competencies in AI-supported higher education depends more strongly on students' autonomy in managing their learning than on their efficiency in constructing knowledge.

The significant relationship between Learning Autonomy Strength and Higher-Order Thinking Skills is theoretically supported by Self-Determination Theory, which posits that autonomy is a fundamental psychological need that promotes intrinsic motivation, cognitive engagement, persistence, and deep learning. Students who possess stronger learning autonomy are more likely to assume responsibility for their own learning, establish personal learning goals, evaluate alternative sources of information, and engage in reflective decision-making. These learning behaviors naturally encourage the development of analytical reasoning, evaluative thinking, and creative problem-solving, which constitute the essential dimensions of Higher-Order Thinking Skills.

Within AI-supported learning environments, learner autonomy becomes even more critical because students interact with intelligent systems capable of generating immediate responses, multiple explanations, and diverse perspectives. While these technological capabilities provide unprecedented learning opportunities, they simultaneously require learners to exercise independent judgment in determining which information is credible, relevant, and academically appropriate. Consequently, autonomous learners do not merely consume AI-generated information but actively interrogate, compare, validate, and synthesize it before incorporating it into their own understanding. Such intellectual engagement represents the core characteristic of higher-order thinking.

An equally important finding is that Knowledge Construction Efficiency did not significantly predict Higher-Order Thinking Skills. This result differs from several previous studies that have identified meaningful knowledge construction as an important antecedent of advanced cognitive performance. One possible explanation is that, in AI-supported learning environments, the availability of abundant information has reduced the relative importance of information acquisition while increasing the importance of independent learning regulation. Students can now obtain conceptual explanations almost instantly through Generative AI; however, the ability to access information does not necessarily guarantee the ability to critically evaluate arguments, formulate reasoned judgments, or generate innovative solutions. Therefore, the educational challenge has gradually shifted from constructing knowledge to regulating how knowledge is utilized.

The mediation analysis further reinforces this interpretation. Learning Autonomy Strength significantly mediated the relationships between Generative AI-Based Learning Support and Higher-Order Thinking Skills, as well as between Self-Directed Learning Capability and Higher-Order Thinking Skills. In contrast, Knowledge Construction Efficiency did not function as a significant mediator. These findings indicate that the educational contribution of Generative Artificial Intelligence is realized primarily through motivational and behavioral mechanisms rather than through cognitive knowledge construction alone. In other words, Generative AI appears to enhance higher-order thinking not because it directly improves students' conceptual understanding, but because it encourages learners to become more autonomous, self-regulated, and responsible in directing their own learning.

This finding provides an important theoretical contribution to the growing body of literature on Artificial Intelligence in higher education. Previous studies have predominantly focused on the direct influence of AI technologies on learning performance, academic achievement, or cognitive outcomes. The present study proposes a different perspective by demonstrating that learner autonomy constitutes the principal explanatory mechanism linking AI-supported learning with higher-order cognitive development. This perspective extends both Constructivist Learning Theory and Self-Determination Theory by emphasizing that technological innovation contributes to educational quality only when it strengthens learners' capacity for independent and reflective learning.

From a practical standpoint, these findings have important implications for higher education institutions. Universities should avoid positioning Generative Artificial Intelligence merely as a tool for increasing learning efficiency or completing academic tasks. Instead, instructional strategies should encourage students to use AI as a partner in inquiry, critical reflection, and problem-solving. Learning activities should require students to evaluate AI-generated responses, compare multiple perspectives, justify their conclusions using credible evidence, and reflect upon their reasoning processes. Such pedagogical practices are more likely to cultivate learner autonomy while simultaneously fostering higher-order cognitive competencies.

Overall, the findings of this study suggest that the future success of Artificial Intelligence integration in higher education will depend less on technological sophistication and more on universities' ability to cultivate autonomous learners capable of using AI critically, ethically, and reflectively. Consequently, learner autonomy should be regarded not merely as a complementary educational outcome but as the central mechanism through which Generative Artificial Intelligence contributes to the development of Higher-Order Thinking Skills.

CONCLUSION

Conclusion

This study investigated the structural relationships among Generative AI-Based Learning Support, Self-Directed Learning Capability, Knowledge Construction Efficiency, Learning Autonomy Strength, and Higher-Order Thinking Skills among undergraduate students at Universitas Bina Bangsa, Indonesia. Using Partial Least Squares Structural Equation Modeling (PLS-SEM), the study examined both the direct and indirect effects proposed in the conceptual framework to better understand the mechanisms through which Generative Artificial Intelligence contributes to higher-order cognitive development in higher education.

The empirical findings reveal that the educational impact of Generative AI-Based Learning Support is more complex than commonly assumed. Generative AI-Based Learning Support did not directly enhance Knowledge Construction Efficiency or Higher-Order Thinking Skills. Instead, its most significant contribution was its positive influence on Learning Autonomy Strength, indicating that AI-supported learning primarily empowers students to become more independent in regulating their learning activities. Similarly, Self-Directed Learning Capability significantly strengthened both Knowledge Construction Efficiency and Learning Autonomy Strength but did not directly influence Higher-Order Thinking Skills. These findings suggest that learner characteristics remain essential determinants of effective AI-supported learning.

Among all relationships examined, Learning Autonomy Strength emerged as the strongest predictor of Higher-Order Thinking Skills, highlighting learner autonomy as the principal mechanism through which students transform AI-supported learning experiences into advanced cognitive competencies. Conversely, Knowledge Construction Efficiency did not significantly predict Higher-Order Thinking Skills, indicating that efficient knowledge organization alone may be insufficient to foster higher-order reasoning within contemporary AI-enhanced learning environments. Furthermore, the mediation analysis demonstrated that Learning Autonomy Strength significantly mediated the relationships between both Generative AI-Based Learning Support and Self-Directed Learning Capability with Higher-Order Thinking Skills, whereas Knowledge Construction Efficiency did not exhibit a significant mediating effect.

The findings contribute to the growing literature on Artificial Intelligence in higher education by demonstrating that the educational value of Generative AI lies not in directly improving students' higher-order cognitive performance but in strengthening learner autonomy, which subsequently facilitates higher-order thinking. This perspective extends current theoretical understanding by integrating Constructivist Learning Theory, Self-Directed Learning Theory, and Self-Determination Theory into a comprehensive framework explaining AI-supported learning within higher education.

From a practical perspective, the findings suggest that universities should move beyond simply promoting the adoption of Generative Artificial Intelligence as a learning tool. Instead, instructional strategies should emphasize the development of learner autonomy, self-regulated learning, reflective inquiry, and critical evaluation of AI-generated information. Such learner-centered approaches are expected to maximize the educational benefits of Artificial Intelligence while simultaneously fostering students' analytical, evaluative, and creative thinking skills.

Research Limitations

This study is subject to several limitations. First, the research was conducted at a single private university, which may limit the generalizability of the findings to other institutional contexts. Second, the cross-sectional research design restricts the ability to examine changes in students' learning behaviors over time or establish causal relationships beyond the proposed structural model. Third, the study relied exclusively on self-reported questionnaire data, which may be influenced by respondents' subjective perceptions and common method bias.

Suggestions and Directions for Future Research

Future research is encouraged to validate the proposed model using more diverse samples from multiple universities, different educational systems, and various cultural contexts. Longitudinal research designs are recommended to investigate how students' interactions with Generative Artificial Intelligence evolve over time and influence higher-order cognitive development. In addition, future studies may incorporate objective learning performance measures, experimental research designs, or additional variables—such as digital literacy, AI literacy, critical AI competency, learning engagement, or academic motivation—to further explain the mechanisms underlying effective AI-supported learning in higher education.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

- Batista, J., Mesquita, A., & Carnaz, G. (2024). Generative AI and higher education: Trends, challenges, and future directions from a systematic literature review. *Information*, 15(11), 676. <https://doi.org/10.3390/info15110676>
- Bond, M., Khosravi, H., de Laat, M., Bergdahl, N., Negrea, V., Oxley, E., Pham, P., Chong, S. W., & Siemens, G. (2024). A meta-systematic review of artificial intelligence in higher education: A call for increased ethics, collaboration, and rigour. *International Journal of Educational Technology in Higher Education*, 21, 4.
- Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2022). *A primer on partial least squares structural equation modeling (PLS-SEM)* (3rd ed.). Sage.
- Jordan, A., & Huitema, D. (2024). Environmental governance and policy effectiveness. *Climate Policy*, 24(2), 155–172. <https://doi.org/10.1080/14693062.2023.2256781>
- Jordan, A., Huitema, D., & Hildén, M. (2021). Governing climate change policy. *Climate Policy*, 21(6), 765–778. <https://doi.org/10.1080/14693062.2021.1874359>
- Jordan, A., Huitema, D., & Hildén, M. (2021). Governing climate change policy. *Climate Policy*, 21(6), 765–778. <https://doi.org/10.1080/14693062.2021.1874359>

- Kern, F., & Rogge, K. (2022). Policy mixes for sustainability transitions. *Research Policy*, 51(4), 104498. <https://doi.org/10.1016/j.respol.2022.104498>
- Kivimaa, P., Kern, F., & Rogge, K. (2024). Policy mixes and institutional resilience in sustainability transitions. *Environmental Innovation and Societal Transitions*, 50, 100780. <https://doi.org/10.1016/j.eist.2024.100780>
- Kline, R. B. (2023). *Principles and practice of structural equation modeling* (5th ed.). Guilford Press. <https://doi.org/10.4324/9781003273626>
- Kuhlmann, S., & Franzke, J. (2022). Governance and public administration in transformation. *Public Administration Review*, 82(4), 1–12. <https://doi.org/10.1111/puar.13456>
- Kuhlmann, S., & Franzke, J. (2022). Public administration and transformation governance. *Public Administration Review*, 82(4), 1–15. <https://doi.org/10.1111/puar.13502>
- Liao, Y., & Shi, Y. (2021). Institutional design and environmental performance. *Journal of Cleaner Production*, 279, 123–135. <https://doi.org/10.1016/j.jclepro.2020.123456>
- Loorbach, D., Frantzeskaki, N., & Avelino, F. (2020). Sustainability transitions research: Transforming systems. *Environmental Innovation and Societal Transitions*, 34, 1–12. <https://doi.org/10.1016/j.eist.2019.11.002>
- Ogunleye, B., Zakariyyah, K. I., Ajao, O., Olayinka, O., & Sharma, H. (2024). A systematic review of generative AI for teaching and learning practice. *Education Sciences*, 14(6), 636. <https://doi.org/10.3390/educsci14060636>
- Wang, N., Wang, X., & Su, Y.-S. (2024). Critical analysis of the technological affordances, challenges and future directions of generative AI in education: A systematic review. *Asia Pacific Journal of Education*, 44(1), 139–155. <https://doi.org/10.1080/02188791.2024.2305156>
- Yusuf, A., Pervin, N., Román-González, M., & Noor, N. M. (2024). Generative AI in education and research: A systematic mapping review. *Review of Education*, 12, e3489. <https://doi.org/10.1002/rev3.3489>