

The Relationship Between Digital Learning Activities and AI Learning Perceptions: The Mediating Role of AI Literacy

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Manuscript received April 17, 2026; revised May 20, 2026; accepted June 22, 2026; published October 16, 2026

Abstract—With the increasing integration of Artificial Intelligence (AI) technologies into education, the relationship between students' perceptions of the use of AI and digital technologies in learning has become an important topic in research on effective instructional design. This study examined the relationship between digital learning activities and AI learning perceptions. Data were collected from 118 undergraduate students enrolled in a general education course at a university in Seoul, South Korea and analyzed using SPSS and PROCESS macro (Model 4). The results indicate that Digital Learning Activities (DLA) significantly predicted AI Literacy (AIL) ($B = 0.449, p < 0.001$), and AIL significantly predicted AI Learning Perceptions (ALP) ($B = 0.681, p < 0.001$). Furthermore, the mediation analysis revealed that digital learning activities were indirectly associated with AI learning perceptions through AI literacy, indicating a full mediation effect. These findings suggest that learners' perceptions of AI-supported learning are shaped not merely by participation in digital activities but also by their level of competence with AI technologies. This study highlights the importance of a competency-based approach in AI-integrated education, emphasizing the need to enhance students' AIL beyond simply increasing opportunities for digital engagement.

Keywords—digital learning activities, Artificial Intelligence Literacy (AIL), AI learning perceptions, higher education, mediation effect

I. INTRODUCTION

The rapid spread of Artificial Intelligence (AI) and digital technologies into education has fundamentally transformed how knowledge is produced, shared, and experienced [1, 2], reshaping the competencies and learning approaches required in higher education. The ability to effectively use and create information in digital environments has thus become a critical learning outcome for university students, and a variety of educational efforts have been made to strengthen AI- and digital-related competencies in higher education.

In this context, Digital Learning Activities (DLA) and AI Literacy (AIL) have emerged as key constructs. In this study, DLA refers to students' engagement in learning processes through the use of digital technologies, including information searching, content creation, and knowledge sharing, and AIL is defined as the ability to understand, use, evaluate, and critically reflect on AI technologies, including their ethical implications [3].

AI-related competencies have been reported to be a crucial factor in learners' attitudes and perceptions. In particular, AI competency has been identified as a mediating factor that interacts with self-efficacy and well-being to foster more positive attitudes toward AI [4].

Researchers have also underscored the transformative role

of AI in higher education. AI tools have been shown to enhance cognitive learning strategies more effectively than metacognitive ones [5], while other studies have urged structured curricular integration and faculty development to facilitate meaningful AI use [6, 7] and the embedding of AIL and intelligent learning systems in broader institutional transformation efforts [8, 9]. These findings highlight that AI use in education should be understood not merely as a technical skill but as a practice embedded in ethical awareness and learning contexts [10].

Despite these advances, researchers have tended to focus primarily on quantitative indicators like the frequency or extent of digital technology use, particularly in digital learning environments, even though participation alone does not guarantee meaningful engagement or successful learning outcomes. Digital learning environments, while offering flexibility and accessibility, have also been shown to present challenges like reduced engagement, limited interaction, and variability in learner persistence [7]. As a result, it remains unclear how such experiences translate into learners' perceptions, for even in the same educational environment, learning outcomes and perceptions may vary depending on students' modes of engagement and actual performance levels. Therefore, there are serious limitations to explaining learning effects based solely on participation experiences.

DLA can be understood as processes through which learners develop competencies via educational participation, institutional engagement, and self-directed learning. However, it remains unclear whether these activities are associated with learners' AI Learning Perceptions (ALP) directly or through intermediate mechanisms. Prior studies have separately examined digital literacy development [11], AI-based learning adoption [12], and learning satisfaction [13], but relatively few studies have investigated these relationships within a single integrated framework. ALP refers to learners' overall evaluative judgments, beliefs, and emotional responses toward the use of artificial intelligence in learning contexts, encompassing perceived usefulness, perceived ease of use, interest, enjoyment, and anxiety related to AI.

In particular, we posit that AIL is likely to function as a key mediating variable in this relationship. For when learners can effectively employ AI technologies in problem-solving, their perceptions of these technologies are more likely to be positive. In other words, perceptions of AI are not merely the result of exposure or experience, but are likely to be grounded in learners' actual level of competence.

Accordingly, to address the limited extent to which these variables were integrated in prior research, this study

examines the structural relationships among DLA, AIL, and ALP in university students with particular attention to the mediating role of AIL, in order to reveal how DLA shapes learners' perceptions through competency-based mechanisms [11–13]. This approach will afford us a more comprehensive understanding of the interrelationships of these variables within a unified analytical framework and of how learners' perceptions are formed in AI-enhanced learning environments, from which we adduce practical implications for effective instructional design in higher education.

Based on this framework, the research model in Fig. 1 was constructed to address the following research questions:

RQ1—H1. Do digital learning activities predict AI literacy?

RQ2—H2. Is AIL significantly associated with ALP?

RQ3—H3. Does AIL mediate the relationship between DLA and ALP?

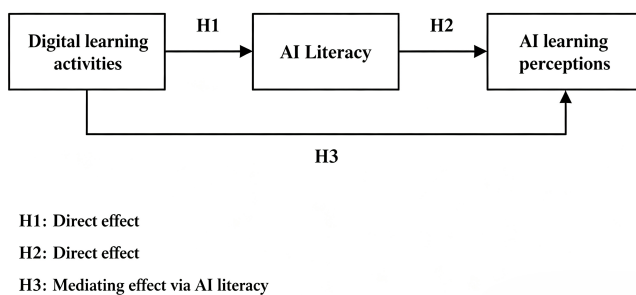


Fig. 1. Research model.

II. LITERATURE REVIEW

A. AI Learning Perception (ALP)

Understanding individuals' attitudes toward and perceptions of AI is critical to the responsible development and adoption of AI technologies [14]. Public perceptions of AI shape its acceptance and usage [15], such that positive perceptions foster trust and facilitate the adoption of AI systems, whereas negative perceptions may arouse resistance and avoidance [16].

In educational contexts, such perceptions have effects beyond simple technology acceptance; they are also important determinants of learning engagement and outcomes. As AI is increasingly integrated into higher education, learners' perceptions of AI-supported learning environments can be considered a key factor in the quality of their learning experiences and their learning outcomes [17]. In this study, this construct is conceptualized as ALP, which reflects their evaluation of how well the learning environment meets their expectations and supports their learning, which in turn influences their continued engagement and acceptance of technology-supported environments [18].

These perceptions can be systematically explained with Self-Determination Theory (SDT), which posits that human motivation and behavior are shaped by the satisfaction of three basic psychological needs: autonomy, competence, and relatedness [19]. Autonomy refers to learners' sense of agency and control over their learning processes, competence involves their perception of effectiveness and mastery, and relatedness reflects their sense of connection and belonging

within the learning environment. When these needs are met within learning environments, learners are more likely to experience intrinsic motivation, form positive perceptions of AI-supported learning, internalize external goals, and exhibit autonomous forms of motivation.

From an SDT perspective, learners' favorable perceptions of AI-supported learning can be understood as a key psychological outcome of learning experiences that enhance their perceived competence and autonomy. In particular, AI-supported environments that provide adaptive feedback, opportunities for self-directed learning, and meaningful interaction can strengthen learners' intrinsic motivation and positive evaluation of AI-supported learning contexts.

Furthermore, higher learner acceptance and positive perceptions are associated with increased participation, sustained engagement, and stronger persistence in learning processes, whereas lower satisfaction or negative perceptions may hinder effective technology use and learning outcomes [20, 21]. Accordingly, learners' perceptions of AI are not merely attitudinal responses but are closely associated with motivational processes grounded in their learning experiences and competencies.

B. AI Literacy (AIL)

A key factor in learners' perceptions of AI is their level of competency in understanding and using AI technologies. AIL has been widely defined as the ability to understand, use, evaluate, and critically reflect on AI systems, including their ethical implications [3]. With the recent rapid integration of AI technologies into education, work, and everyday life, AIL has been increasingly recognized as a critical competence in contemporary society [22, 23]. This competence is particularly important in higher education, as students are expected to engage with AI-supported learning environments and prepare for AI-mediated professional practices [24].

Higher levels of AI-related competency reduce the anxiety and uncertainty associated with technology use and enhance confidence in interacting with AI systems [25]. Moreover, competency crucially shapes attitudes toward technology, as individuals with a greater understanding of a technology are more likely to develop positive perceptions of it [26, 27].

In addition, digital literacy research suggests that competency facilitates learners' effectively engagement with technology-mediated environments and ability to sustain meaningful learning processes [13, 28, 29]. Learners with higher levels of digital literacy are more likely to demonstrate stronger engagement and more positive learning experiences, whereas lower levels of literacy may hinder effective participation and lead to worse outcomes [30].

The mediating role of AI competency in the formation of attitudes toward AI has also received scholarly attention. For instance, Naisch *et al.* [4] demonstrated that AI competency interacts with self-efficacy and well-being, ultimately fostering more positive attitudes toward AI. Similarly, Chiu [31] proposed a competency framework that integrates the cognitive, social, and technical dimensions of competency for effective interaction with AI systems, while Pramod [32] highlighted the importance of ethical awareness and data responsibility in AI use. This line of research further suggests that competency-related variables often exert their influence indirectly through intermediate mechanisms, as via engagement, rather than solely through strong direct

effects [33, 34].

AIL is increasingly conceptualized as a multidimensional construct that encompasses cognitive, technical, and ethical dimensions of AI use. In particular, contemporary frameworks emphasize not only the ability to operate AI tools but also the capacity to critically evaluate AI-generated information and use AI technologies responsibly in various contexts [31, 32]. AIL thus functions as a key explanatory mechanism that translates learning experiences into perceptions rather than merely representing a set of technical skills.

C. Digital Learning Activities (DLA)

Competencies are developed through learners' active engagement and participation. DLA engages learners in learning processes with digital technologies, including information searching, content creation, and knowledge sharing.

From a learning perspective, behavioral engagement is central to competency development. Participation in digital and AI-enhanced learning environments has been reported not only to contribute to the development of technical skills but also to enhance cognitive learning strategies [5]. Furthermore, the structured integration of AI into educational curricula has been shown to enhance student creativity, engagement, and learning effectiveness [6, 7].

In this context, DLA can be understood as a multidimensional construct encompassing behavioral participation, cognitive investment, and emotional involvement in learning processes [35], where higher levels of engagement are associated with stronger problem-solving abilities, greater persistence, and more effective knowledge retention and application [13, 36]. Moreover, increased engagement in technology-mediated learning environments has been consistently linked to improved academic performance and more positive learning experiences [37].

In addition, institutional efforts to integrate AIL and intelligent learning systems into educational environments have highlighted the importance of digital engagement [8, 9]. DLA also shapes learners' motivation, attitudes, and satisfaction, as active participation in learning processes is closely associated with more positive perceptions of learning environments [38], and engagement-related factors have been reported to show significant associations with learners' satisfaction and continued use of digital learning systems [39]. DLA is thus foundational for the development of AI-related competencies and meaningful learning experiences.

D. Relationships among Digital Learning Activities, AI Literacy, and AI Learning Perceptions

Previous research has increasingly examined the relationships among DLA, AIL, and learning-related perceptions in AI-supported educational contexts. However, these variables have often been investigated separately, resulting in a fragmented understanding of how learning activities shape learners' perceptions.

First, a positive relationship between DLA and AIL has been consistently identified. Engagement in digital learning environments, particularly through activities involving AI-supported tools, information searching, and content creation, has been shown to enhance learners' AI-related

competencies: Learners who participate more actively in such activities tend to demonstrate higher levels of AIL [11]. This suggests that DLA is a significant predictor of AIL in higher education.

Second, AIL is closely associated with AI-related perceptions and outcomes. Digital literacy influences AI adoption through mediating mechanisms such as perceived usefulness and perceived ease of use [12], and its effects on learning outcomes are often indirect [13, 40]. Taken together, these findings indicate that higher levels of AIL are associated with more positive ALP.

Third, DLA has also been shown to be directly related to ALP. Participation in AI-supported learning activities is associated with more positive perceptions of AI-supported learning and increased confidence in using AI tools. Learners, particularly lower-proficiency ones, who actively engage in AI-integrated tasks tend to report more favorable learning perceptions [41]. These findings support a direct relationship between DLA and ALP.

Taken together, prior research suggests that DLA, AIL, and ALP are interconnected rather than independent. Existing studies have demonstrated positive relationships between DLA and AIL [11], AIL and AI-related perceptions [4, 12, 40], and DLA and ALP [41]. However, these variables have typically been examined separately, resulting in a fragmented understanding of how digital learning experiences are associated with learners' perceptions of AI-supported learning. In particular, the mediating role of AIL in the relationship between DLA and ALP remains insufficiently explored. Therefore, the structural relationships among these variables merit examination within a single integrated framework.

III. MATERIALS AND METHODS

A. Participants

The participants in this study were undergraduate students enrolled in a general English course at a four-year university in Seoul, South Korea, who had a wide range of academic majors and proficiency levels, resulting in a heterogeneous sample. This characteristic reduces disciplinary bias and allows the sample to reflect typical learner characteristics within higher education contexts.

Participants were recruited from students enrolled in the course using convenience sampling and were administered a survey at the end of the 2025 fall semester so that their responses would reflect their learning experiences over the course of the semester. Before data collection, participants were provided with a detailed explanation of the study's purpose and procedures. Participation was entirely voluntary, and students were informed that their participation would not affect their grades or course evaluations. They were also informed of their right to withdraw from the study at any time without penalty.

All responses were collected anonymously, and the data were used solely for academic research purposes. No personally identifiable information was collected at any stage of the study. Only responses from participants who provided informed consent were included in the final analysis.

A total of 118 valid responses were used for analysis. The mean age of the participants was 20.66 years (SD = 1.68),

with an age range from 19 to 26 years. The sample consisted of 71 male students (60.2%) and 47 female students (39.8%).

B. Measures

The instruments in this study were based on SDT, developed upon the assumption of causal relationships among DLA, AIL, and ALP. According to SDT, learners' perceptions and motivation are shaped by the fulfillment of basic psychological needs—autonomy, competence, and relatedness [19]. In particular, perceived competence crucially shapes how learners evaluate their learning experiences. From this perspective, learners' perceptions of AI-supported learning are understood not merely as attitudes but as psychological outcomes formed through learning experiences and competency development.

A structured questionnaire was used to measure university students' DLA (Table A1), AIL (Table A2), and ALP (Table A3). The survey items were adapted from prior studies and refined to fit the purpose of this study. All items were measured using a five-point Likert scale (1 = strongly disagree, 5 = strongly agree).

DLA refers to the extent to which learners engage in learning processes using digital technologies, including participation in activities related to information searching and content creation. This construct was measured using three items: (1) participation in digital device-related training, (2) participation in relevant institutional activities, and (3) self-directed effort, adapted from prior studies on digital learning engagement and technology-supported learning behaviors [42, 43].

Each item was designed to reflect learners' actual level of engagement, with higher scores indicating greater participation in DLA. The reliability of this scale was acceptable (Cronbach's $\alpha = 0.772$).

AIL refers to learners' ability to search for, analyze, and evaluate information in AI environments and generate new content accordingly. This construct was measured using 12 items covering multiple dimensions of AI-related competencies, including information search and collection, evaluation and management, data analysis and representation, and digital content creation. These items were adapted and refined from prior studies of and established frameworks for AI and digital competence, particularly those emphasizing information literacy, problem solving, and content creation skills [3, 22, 23].

Each item reflects the competencies required in real learning contexts, with higher scores indicating a higher level of AIL. The reliability of this scale was excellent (Cronbach's $\alpha = 0.953$).

ALP refers to learners' perceptions of and attitudes toward learning experiences involving digital technologies and AI. This construct was measured using six items that assessed the perceived impact of AI use on learning interest, comprehension, self-directed learning, and time efficiency. The items were constructed based on established models of technology acceptance and learning-related evaluation, reflecting key dimensions such as usefulness, ease of use, and behavioral intention [44, 45].

Each item was designed to capture learners' perceived learning outcomes, with higher scores indicating more positive perceptions of AI-supported learning. The reliability

of this scale was also excellent (Cronbach's $\alpha = 0.941$).

C. Data Analysis

The collected data were analyzed using SPSS 28.0 and Hayes' PROCESS macro [46]. First, descriptive statistics were calculated to examine the distributional characteristics of the main variables, and Cronbach's α coefficients were calculated to assess the internal consistency of each scale. Normality was examined using skewness (0.05 to 0.15) and kurtosis (-1.04 to -0.96) values, indicating acceptable normality for parametric analysis. Multicollinearity was assessed using Variance Inflation Factor (VIF) values (2.06), suggesting no multicollinearity concerns. Next, Pearson correlation analysis was performed to examine the relationships among DLA, AIL, and ALP.

To test the mediating effect of AIL on the relationship between DLA and ALP, PROCESS macro Model 4 was employed [46]. The mediation analysis focused on the following paths: (1) the effect of DLA on AIL (Path a), (2) the effect of AIL on ALP (Path b), (3) the total effect of DLA on ALP (Path c), and (4) the direct effect of DLA on ALP while controlling for AIL (Path c'). The statistical significance of the indirect effect was tested using bootstrapping with 5000 resamples. A mediation effect was considered significant if the 95% confidence interval did not include zero. All statistical tests were conducted at a significance level of 0.05.

IV. RESULT

A. Descriptive Statistics and Correlation Analysis

Pearson correlation analysis was conducted to examine the relationships among DLA, AIL, and ALP. As presented in Table 1, the descriptive statistics and correlation results indicate that all variables were positively and significantly correlated. Specifically, a moderate positive correlation was found between DLA and AIL ($r = 0.494$, $p < 0.001$), suggesting that students who more actively engaged in DLA tended to exhibit higher levels of AIL.

Table 1. Correlations among the main variables

Variables	M (SD)	DLA	AIL	ALP
DLA	3.867 (0.736)	1	0.494***	0.329***
AIL	3.886 (0.684)	0.494***	1	0.651***
ALP	3.895 (0.729)	0.329***	0.651***	1

Note: *** $p < 0.001$

In addition, DLA showed a significant positive correlation with ALP ($r = 0.329$, $p < 0.001$), indicating that engagement in DLA is associated with a more favorable evaluation of AI-supported learning. However, the magnitude of this relationship was smaller than the other correlations, suggesting that participation alone may not fully explain learners' perceptions.

Notably, the strongest correlation was observed between AIL and ALP ($r = 0.651$, $p < 0.001$), indicating a close association between students' AIL and their perceptions of AI-supported learning, such that higher AIL is linked to more positive evaluations of AI-based learning experiences.

Overall, the results confirm that DLA is significantly related to AIL and ALP, while AIL demonstrates a particularly strong association with ALP. These findings not only establish the baseline relationships among the variables

but also indicate that the data meet the statistical assumptions of mediation analysis.

B. Mediation Analysis

To examine the mediating role of AIL on the relationship between DLA and ALP, mediation analysis was conducted using PROCESS macro Model 4 [46].

First, the effect of DLA on AIL (Path a) was tested. As shown in Table 2, the results indicated that DLA significantly predicted AIL ($B = 0.449$, $t = 6.113$, $p < 0.001$), suggesting that greater engagement in DLA is associated with higher levels of AIL. Next, the total effect of DLA on ALP (Path c) was examined. The results showed that DLA significantly and positively predicted ALP ($B = 0.315$, $t = 3.751$, $p < 0.001$), indicating that DLA are associated with more positive perceptions of AI-supported learning.

When both DLA and AIL were simultaneously entered into the model, AIL remained a significant predictor of ALP ($B = 0.681$, $t = 7.940$, $p < 0.001$), whereas the direct effect of DLA on ALP (Path c') was no longer significant ($B = 0.010$, $t = 0.122$, $p = 0.903$), as presented in Table 2. This pattern suggests that the relationship between DLA and ALP is fully accounted for by AIL.

Table 2. Mediation regression results

Model	DV	R ²	IV	B	SE	t
Model 1	AIL	0.244	DLA	0.449	0.074	6.113***
Model 2	ALP	0.108	DLA	0.315	0.084	3.751***
Model 3	ALP	0.424	DLA	0.010	0.078	0.122
			AIL	0.681	0.086	7.940***

Note: DV = Dependent Variable; IV = Independent Variable, *** $p < 0.001$.

To further examine the indirect effect, bootstrapping with 5000 resamples was conducted. As shown in Table 3, the indirect effect ($a \times b$) was 0.303, and the 95% confidence interval [0.190, 0.427] did not include zero, indicating that the mediation effect was statistically significant.

Table 3. Indirect effect (Bootstrap)

Path	Effect	95% CI
DLA $\rightarrow$ AIL $\rightarrow$ ALP	0.303	[0.190, 0.427]

These relationships are visually summarized in Fig. 2, which illustrates the mediation model and standardized path coefficients. These findings indicate that AIL fully mediates the relationship between DLA and ALP. In other words, DLA is associated with learners' perceptions of AI-supported learning primarily through their impact on AIL, rather than by exerting a direct effect.

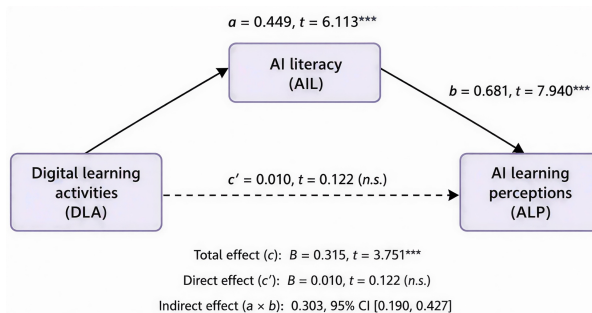


Fig. 2. Mediation model (** $p < 0.001$).

V. DISCUSSION

The present study examined the relationships among DLA,

AIL, and ALP, with a focus on the mediating role of AIL. The findings hold several important implications.

First, the findings regarding RQ1 suggest that engagement in technology-mediated learning processes is closely associated with the development of learners' AI-related competencies. This finding is consistent with prior research emphasizing the role of behavioral engagement in competency development [5–7]. Notably, this study conceptualized DLA not merely as the frequency of technology use but as a broader construct encompassing participation in learning processes and self-directed effort. In this regard, the results provide empirical support for the idea that the quality and nature of engagement, rather than mere exposure, are fundamental conditions for competency development. This extends prior research by highlighting the importance of meaningful engagement in digital learning environments.

Second, the findings related to RQ2 indicate that learners with higher levels of AIL tend to report more favorable perceptions of AI-supported learning. This finding aligns with research indicating that technological competence strongly affects attitudes toward technology [23, 24]. Furthermore, by conceptualizing AIL as a multidimensional construct encompassing information search, evaluation, and content creation, the present study demonstrates that positive perceptions of AI are grounded in learners' actual ability to perform meaningful tasks, rather than in simple familiarity or exposure, underscoring the importance of competency-based approaches in AI-integrated education.

Third, AIL was found to fully mediate the relationship between DLA and ALP (RQ3). In other words, DLA did not directly predict learners' perceptions of AI-supported learning but was indirectly associated with ALP through AIL. This finding is consistent with earlier findings that the effects of digital competencies on learning-related outcomes are often transmitted through intermediate mechanisms [12, 13], suggesting that learners' perceptions are not formed solely through participation or experience but are shaped through the development of competencies that enable effective engagement with AI technologies. Importantly, although a significant correlation between DLA and ALP was observed, the direct effect was non-significant in the mediation model. This pattern indicates that the relationship between experience and perception is fully transmitted through competency, offering a more nuanced understanding than the commonly assumed direct link between usage and positive attitudes.

These findings can be further interpreted through the lens of SDT. According to SDT, learners' motivation and perceptions are shaped by the fulfillment of basic psychological needs, particularly the need for competence [19]. The mediating role of AIL identified in this study suggests that DLA contributes to learners' perceived competence, which in turn fosters greater acceptance of AI-supported learning. From a cognitive perspective, AIL may function as a mechanism through which learners develop the capacity to evaluate, organize, and apply information obtained from AI systems [23, 24]. As learners become more capable of effectively using AI-generated information, they may be more likely to perceive AI-supported learning as useful and beneficial [31].

This finding further supports the relevance of SDT in explaining learners' perceptions in AI-supported learning environments. From an SDT perspective, the mediating role of AIL suggests that learners' perceptions of AI-supported learning are associated with the development of competence through meaningful digital learning experiences. This finding supports the relevance of SDT in explaining how learning experiences may be translated into more positive perceptions of AI-supported learning environments. Unlike previous studies that have primarily focused on AI literacy [3, 22, 23], attitudes toward AI [4, 17], or perceptions of AI-supported learning [41] as separate constructs, the present study integrated DLA, AIL, and ALP within a single analytical framework. Methodologically, the study extends prior research by empirically testing the mediating role of AIL, thereby providing a more nuanced explanation of how digital learning experiences are associated with learners' perceptions of AI-supported learning.

Overall, this study demonstrates that learners' perceptions of AI-supported learning are shaped by a mechanism in which DLA contributes to competency development, which in turn is associated with perception. By identifying the mediating role of AIL, the findings offer a more comprehensive understanding of how learning experiences are translated into perceptions in AI-enhanced educational contexts.

VI. CONCLUSION

This study examined the structural relationships among DLA, AIL, and ALP among university students, with a focus on the mediating role of AIL. The findings suggest that DLA, AIL, and ALP are closely interconnected and that AIL plays an important role in explaining learners' perceptions of AI-supported learning.

Learners' perceptions of AI-supported learning are not directly shaped by participation alone but are formed through their actual level of competence and ability to effectively use AI technologies. In other words, simply increasing opportunities for digital engagement may not suffice to enhance learners' perceptions of AI-based learning. Rather, a more systematic approach that fosters learners' AIL is required. From an SDT perspective, this implies that educational practices should focus on creating learning environments that support learners' basic psychological needs as well as provide access to AI tools. In particular, the fostering of learners' sense of competence through structured and meaningful AI-related tasks and support of autonomy through opportunities for self-directed learning may enhance learners' perceptions and motivation in AI-supported learning contexts.

In line with this, the present findings highlight the need to shift from a participation-based approach to a competency-based approach in AI-integrated education; higher education should not treat AI as a mere tool but instead design learning environments that promote practical competencies like problem-solving, information analysis, and content creation. Such environments are also likely to promote more autonomous and internally regulated forms of motivation, which are associated with sustained engagement and more positive learning experiences. In addition, it is important to create learning environments that promote

learners' sense of competence, which critically shapes their perceptions and motivation.

Despite its contributions, this study has several limitations. First, the sample was drawn from a single university using convenience sampling, which may limit the generalizability of the findings to broader higher education contexts. In addition, the relatively small sample size should be borne in mind when interpreting the results. Second, the data were based on self-reported measures, which may reflect participants' subjective perceptions. In addition, although the measurement instruments were adapted from previously validated studies and frameworks, additional validation procedures beyond scale adaptation were not conducted in the present study. Furthermore, although SDT was used as a theoretical lens to interpret the findings, its core constructs, such as autonomy and competence, were not directly measured in this study. Therefore, the SDT-based interpretations should be viewed with caution. In addition, the cross-sectional nature of the study limits the ability to draw conclusions regarding the directionality of the relationships among the variables. Future research should consider more diverse samples across institutions and learning contexts, as well as incorporating objective measures of learning performance.

Nevertheless, this study makes a meaningful contribution by providing an integrated analysis of the relationships among DLA, AIL, and ALP and by empirically demonstrating the mediating role of AIL. Future research should further explore the complex interplay between learners' competencies and perceptions in AI-enhanced educational environments.

APPENDIX: QUESTIONNAIRE ITEMS

Table A1. Digital Learning Activities (DLA)

No.	Item
1	I participate in educational activities related to the use of generative AI and digital technologies.
2	I participate in curricular or extracurricular activities related to generative AI and digital technologies (e.g., clubs, comparison activities).
3	I make self-directed efforts to improve my competencies in using generative AI and digital technologies (e.g., watching YouTube videos or engaging in individual learning activities).

Note: All items were measured using a 5-point Likert scale.

Table A2. AI Literacy (AIL)

No.	Item
1	I can use search engines to effectively search for information on the internet.
2	I can use AI-based search services to search for information.
3	I can use digital devices or services to manage data systematically.
4	I can evaluate whether collected information contains useful content.
5	I understand the importance of protecting intellectual property rights when creating digital content (e.g., videos).
6	I can critically evaluate whether digital information contains errors or hidden biases.
7	I understand how to follow procedures to analyze data.
8	I can use software such as spreadsheets to visualize or analyze data.
9	I can use document editing programs (e.g., Hangul or MS Word) proficiently.
10	I understand various methods for indicating copyright when creating digital content.
11	I can express my ideas or information using digital content.
12	I am interested in tools or technologies used to create digital content.

Note: All items were measured using a 5-point Likert scale.

Table A3. AI Learning Perceptions (ALP)

No.	Item
1	AI-supported learning is enjoyable.
2	AI-supported learning helps me understand learning content better.
3	AI-supported learning helps me remember what I have learned.
4	AI-supported learning helps me understand what others are saying.
5	AI-supported learning helps me study at my own pace.
6	AI-supported learning helps improve my self-directed learning.

Note: All items were measured using a 5-point Likert scale.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

S.P. conceived the study, collected and analyzed the data, and wrote the manuscript. M.K. supervised the study, reviewed and revised the manuscript, and served as the corresponding author. Both authors approved the final manuscript.

FUNDING

This work was supported by a research grant from Sehan University in 2026.

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