

# AI Literacy as an Enabling Capability for Higher-Order Thinking: A Structural Model of Multidimensional Student Engagement

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## Keywords:

artificial intelligence literacy; student engagement; critical thinking; logical reasoning; higher order thinking skills; higher education

## ABSTRACT

The integration of artificial intelligence (AI) in higher education is transforming learning processes and requires students to develop adequate AI literacy to effectively engage with AI-mediated learning environments. However, limited research has examined how AI literacy contributes to the development of higher-order thinking skills through student engagement mechanisms. This study aims to investigate the role of AI literacy in enhancing critical thinking and logical reasoning, with multidimensional student engagement behavioral, cognitive, and social engagement as mediating variables. A quantitative research design was employed using a structural equation modeling (SEM) approach to analyze the relationships among the proposed constructs. The findings reveal that AI literacy significantly influences students' behavioral, cognitive, and social engagement in learning activities. Furthermore, the three dimensions of engagement significantly contribute to the development of higher-order thinking skills, with cognitive engagement showing the strongest effect. The results also indicate that AI literacy has a direct and significant impact on both critical thinking and logical reasoning. These findings suggest that AI literacy functions as an enabling capability that supports deeper learning processes through increased student engagement. This study contributes to the literature by providing empirical evidence of the mechanism through which AI literacy promotes higher-order thinking in AI-supported educational environments and highlights the importance of integrating AI literacy development into higher education curricula.

## Info Article

Accepted: 2025-12-13

Revised: 2026-01-24

Approved: 2026-02-26



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## INTRODUCTION

The integration of Artificial Intelligence (AI) in higher education has changed the learning process, where AI not only functions as a tool but also as a cognitive partner in the student's thinking process (Andrian et al., 2025; Chan, 2026). In this context, AI literacy is an important competency that includes conceptual understanding, critical use, and ethical awareness of technology (Sari et al., 2025). However, the literature shows that there is a debate about the impact of AI on students' thinking skills, because in addition to improving learning efficiency, the use of non-reflective AI has the potential to cause cognitive offloading and technology dependence (Andrian et al., 2025).

The rapid advancement of artificial intelligence (AI) technologies has significantly reshaped the landscape of higher education, transforming how students access information, construct knowledge, and engage in learning processes. AI tools such

as intelligent tutoring systems, generative AI, and automated feedback platforms are increasingly integrated into academic activities, enabling more personalized and efficient learning experiences. However, this transformation also introduces a critical phenomenon: while AI has the potential to enhance learning efficiency, it may simultaneously reduce students' cognitive engagement if used uncritically. This duality creates a pressing need to understand how students can meaningfully interact with AI technologies without compromising their higher-order thinking skills.

Previous research is still limited in elucidating the mechanisms linking AI literacy to higher-level thinking abilities (Salido et al., 2025; Sari et al., 2025). In fact, student engagement, which includes behavioral, cognitive, and social dimensions, is known to play an important role in learning success (Bond et al., 2020; Fredricks et al., 2004; Kohnke et al., 2023). Therefore, this study developed a structural model that examines the mediating role of behavioral engagement, cognitive engagement, and social engagement in the relationship between AI literacy and critical thinking and logical reasoning (Lu et al., 2025; Qadeer, 2025). This research contributes by placing AI literacy as a basic capability in AI-based learning and explaining the role of student engagement as a multidimensional mediation mechanism in the development of students' high-level thinking skills (Salido et al., 2025)

The urgency of this study lies in the rapid and widespread adoption of AI technologies in higher education. Without a clear understanding of how AI literacy shapes cognitive development, there is a risk that AI integration may lead to superficial learning rather than deep thinking. Therefore, identifying the mechanisms that support meaningful engagement is critical for both educational practice and policy development.

This study offers a novel contribution by developing and empirically testing a structural model that simultaneously positions behavioral, cognitive, and social engagement as multidimensional mediators between AI literacy and two components of higher-order thinking skills, namely critical thinking and logical reasoning. This integrated model provides a more comprehensive understanding of the learning mechanisms in AI-supported environments.

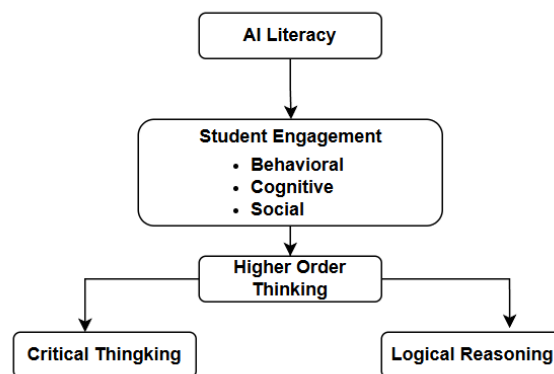
Artificial intelligence literacy refers to understanding basic concepts of AI, the ability to use AI-based tools effectively, and awareness of its ethical and social implications (Chiu, 2025; Long & Magerko, 2020). In the context of education, AI literacy allows students to interact more meaningfully with AI-based learning environments and utilize the technology to support knowledge construction and problem-solving (Immanuella, 2023). Students with higher AI literacy tend to have greater confidence in using AI systems, so they can increase behavioral engagement through active participation and involvement in learning activities (Appleton et al., 2008; Yilmaz Soylu et al., 2025).

In addition, AI literacy also has the potential to increase cognitive engagement because students are better able to critically evaluate the information generated by AI and engage in more in-depth cognitive processing (Fredricks et al., 2004). On the other hand, AI literacy can also encourage social engagement through the use of AI technology as a

means of collaboration and knowledge exchange (Yilmaz Soylu et al., 2025). Previous research has shown that technology literacy and digital competence are important factors that affect student engagement in a technology-based learning environment (Immanuella, 2023). Therefore, this study proposes a hypothesis related to the relationship between AI literacy and various dimensions of student engagement (Fredricks et al., 2004; Immanuella, 2023)

*Student engagement* is widely recognized as an important factor that influences the achievement of high-level learning outcomes, including critical thinking skills (Bond et al., 2020; Fredricks et al., 2004). This engagement reflects the extent to which students actively participate in learning activities, invest cognitive efforts, and engage in social interaction within the learning environment (Kim, & Reschly, 2008) (Appleton et al., 2008). Previous research emphasizes that *student engagement* is a multidimensional construct consisting of behavioral, cognitive, and social dimensions, where each dimension contributes differently to students' cognitive development (Fredricks et al., 2004; Kohnke et al., 2023)

*Logical reasoning* represents an individual's ability to systematically analyze information, identify relationships between concepts, and draw valid conclusions (Kuhn, 2000). In higher education, this ability is one of the important components of *higher-order thinking skills*. *Student engagement* is thought to play an important role in the development of logical reasoning (Fredricks et al., 2004). *Behavioral engagement* provides opportunities for students to practice solving problem-solving tasks in a structured manner, *cognitive engagement* encourages deeper analytical processing and systematic thinking strategies, while *social engagement* facilitates reasoning through dialogue, argumentation, and collaboration, allowing students to consider different perspectives and strengthen their reasoning structure (Appleton et al., 2008).



**Figure 1.** Conceptual Model

The primary objective of this study is to examine the role of AI literacy in fostering higher-order thinking skills, specifically critical thinking and logical reasoning, through the mediating mechanism of multidimensional student engagement (behavioral, cognitive, and social). This study aims to provide empirical evidence on how AI literacy

functions not merely as a technical competency but as an enabling capability that supports deeper cognitive processes in AI-mediated learning environments.

The benefits of this research are both theoretical and practical. From a theoretical perspective, this study contributes to the literature by integrating AI literacy, student engagement, and higher-order thinking into a unified structural model, thereby offering a more comprehensive understanding of learning mechanisms in the digital era. From a practical perspective, the findings provide valuable insights for educators, curriculum designers, and policymakers in designing AI-integrated learning environments that promote meaningful engagement and cognitive development rather than passive reliance on technology.

Furthermore, this study has important implications for educational practice and policy. It suggests that the development of AI literacy should go beyond operational skills and include critical and reflective competencies that encourage students to actively evaluate and utilize AI outputs. Additionally, it highlights the need for pedagogical strategies that prioritize cognitive engagement, such as problem-based learning, reflective tasks, and collaborative reasoning activities. By emphasizing these aspects, higher education institutions can ensure that AI serves as a cognitive enhancer rather than a cognitive substitute, ultimately supporting the development of students' higher-order thinking skills in an increasingly AI-driven academic environment.

## **METHOD**

### **Research Design**

This study uses a quantitative approach with an explanatory design to test the causal relationship between *AI literacy*, *student engagement* (which includes *behavioral engagement*, *cognitive engagement*, and *social engagement*), as well as high-level thinking skills consisting of *critical thinking* and *logical reasoning*. This approach was chosen because it is suitable for testing conceptual models involving multiple latent constructs as well as structural relationships occurring simultaneously.

Data analysis was carried out using *the Structural Equation Modeling Partial Least Squares* (SEM-PLS) method. This method was chosen because it has the advantage of analyzing predictive models, involving complex latent constructs, and relatively robust against abnormal data distribution assumptions. In addition, SEM-PLS also allows researchers to simultaneously evaluate measurement *models* and structural models.

### **Research Context and Participants**

This research was carried out at one of the universities in West Java Province, Indonesia, which has integrated digital technology and artificial intelligence in various learning activities. The institutional context provides a relevant environment to examine the relationship between AI literacy, student engagement, and the development of higher-level thinking skills. The research participants are undergraduate students who are used to using AI technology, both for academic purposes such as information search, problem-solving, and academic writing as well as for non-academic activities. The sample

selection was carried out using *purposive sampling* techniques with several main criteria, namely: (1) status as an active student, (2) having experience using AI in the context of learning, and (3) willing to participate voluntarily by filling out a research questionnaire. This approach is considered appropriate because this study does not aim to generalize the findings to a population that is not yet familiar with AI technology, but rather to understand the dynamics of learning engagement and high-level thinking skills in a group of students who have had intensive exposure to the use of AI.

### **Instruments and Measures**

The research instrument was developed in the form of a structured questionnaire to measure all constructs used in this study. Each variable is operationalized into several measurement indicators that are assessed using a five-point Likert scale, ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). The measurement items were adapted from various previous studies related to AI literacy, *student engagement*, critical thinking skills, and logical reasoning. The adaptation process is carried out to ensure the suitability of the indicators with the learning context mediated by AI technology in higher education. Details of the measurement indicators for each construct are presented in Table 1.

**Table 1.** Research Instrument and Measurement Indicators

<b>Variable</b>	<b>Measurement Indicators</b>	<b>Source</b>
<b>AI Literacy</b>	Understand the basic concepts and functions of artificial intelligence in learning	Yilmaz Soyly et al. (2025) ; Zhan (2022) ; Long & Magerko (2020)
	Ability to critically evaluate AI-generated information	
	Awareness of the ethical and responsible use of AI technology	
<b>Behavioral Engagement</b>	Active participation in learning activities	Fredricks et al. (2004)
	Efforts to complete learning assignments	
	Perseverance in academic activities	
<b>Cognitive Engagement</b>	Ability to understand complex learning materials	Bond et al. (2020)
	Integrate new information with previous knowledge	
	Using <i>deep learning strategies</i>	
<b>Social Engagement</b>	Interaction with peers during learning activities	Kohnke et al. (2023)
	Collaboration in completing academic assignments	
	Share ideas and perspectives with classmates	

Variable	Measurement Indicators	Source
<b>Critical Thinking</b>	Evaluating the credibility of information	Kohnke et al. (2023)
	Analyze arguments logically	
	Draw evidence-based conclusions	
<b>Logical Reasoning</b>	Identifying logical relationships between ideas	Yilmaz Soyulu et al. (2025)
	Comparing alternative solutions logically	
	Draw rational conclusions based on analysis	

Source: Data Processed

### Data Collection Procedure

This study involved 437 respondents consisting of undergraduate students who have experience using artificial intelligence devices in learning activities. Respondents were selected using *purposive sampling* techniques with the main criterion that participants had used AI-based learning tools such as ChatGPT or other AI applications in academic activities. Data collection was carried out through an online questionnaire distributed using the Google Forms platform in the period from February to April 2026. All participants participated voluntarily after expressing consent to participate in the study.

The sample size used in this study met the recommended requirements for *Structural Equation Modeling* (SEM) analysis. According to Hair & Alamer (2022) SEM analysis generally requires a minimum sample size of between 100 to 200 respondents or at least 5–10 observations for each measurement indicator. In this study, the measurement model consists of 18 indicators, so that the recommended minimum sample size is in the range of 90 to 180 respondents. With a total of 437 participants, the sample size of this study can be considered adequate and meets the recommended criteria for SEM analysis.

**Table 2.** Respondent Characteristics

Characteristic	Category	Frequency	Percentage
Gender	Male	228	52.2%
	Female	209	47.8%
Experience Using AI	< 1 year	156	35.7%
	1–2 years	181	41.1%
	> 2 years	100	22.9%

Source: Data Processed

### Control Variable

To minimize potential bias in the structural relationships tested, this study included several control variables in the analysis. Specifically, the variables of gender, age, and experience using AI devices were controlled in the research model. These demographic characteristics are considered because they have the potential to affect the level of student engagement and high-level thinking skills. By controlling these variables, the analysis is expected to more accurately isolate the influence of *AI literacy* on *student engagement, critical thinking, and logical reasoning*

### **Data Analysis Technique**

Data analysis was carried out using SmartPLS through two main stages, namely the evaluation of the measurement model and the structural model. Evaluation of the measurement model includes: internal reliability tests using Cronbach's Alpha and Composite Reliability, convergent validity tests using Average Variance Extracted (AVE), and discriminant validity tests using Heterotrait Monotrait ratio (HTMT). Structural model evaluation included testing the path coefficient and hypothesis significance through bootstrapping, power measurement of the model using  $R^2$ , effect size ( $f^2$ ) analysis to assess the relative contribution of each construct, and predictive relevance ( $Q^2$ ) testing using the blindfolding procedure. This approach allows for a thorough evaluation of the predictive power and stability of the proposed model.

## **RESULTS AND DISCUSSION**

### **Measurement Model Evaluation**

#### **1. Indicator Reliability**

The measurement model is evaluated by examining the *outer loading* of all indicators to assess the validity of the convergence. The results show that most indicators show a strong charge above the recommended threshold of 0.70, which indicates a satisfactory convergent validity across the construct. In particular, *Behavioral Engagement, Cognitive Engagement, Critical Thinking, and Logical Reasoning* exhibit consistently high charges, reflecting robust and reliable measurements of student engagement and high-level cognitive skills in the context of AI literacy learning.

**Tabel 3.** Outer loadings of measurement indicators

	<b>AI Literacy</b>	<b>Behavior Engagement</b>	<b>Cognitive Engagement</b>	<b>Critical Thinking</b>	<b>Logical Reasoning</b>	<b>Social Engagement</b>
<b>AIL 1</b>	0,751					
<b>AIL 2</b>	0,580					
<b>AIL 3</b>	0,782					
<b>AIL 4</b>	0,775					
<b>BE1</b>		0,711				
<b>BE2</b>		0,866				
<b>BE3</b>		0,867				
<b>BE4</b>		0,843				
<b>CE1</b>			0,815			

	AI Literacy	Behavior Engagement	Cognitive Engagement	Critical Thinking	Logical Reasoning	Social Engagement
CE2			0,882			
CE3			0,845			
CE4			0,872			
CT1				0,867		
CT2				0,826		
CT3				0,855		
CT4				0,831		
LR1					0,870	
LR2					0,778	
LR3					0,849	
SE1						0,752
SE2						0,683
SE3						0,589
SE4						0,650

Source: Data Processed

Some indicators in the AI Literacy and Social Engagement construct have loading values slightly below the ideal threshold, but are still maintained based on theoretical and contextual considerations. This is due to the abstract characteristics of AI literacy and AI-based learning activities that tend to be more individualized, so social interaction is relatively limited. In the PLS-SEM literature, indicators with loads above 0.50 are still acceptable in exploratory studies, so the measurement model in this study is considered adequate to proceed to structural model analysis.

### Internal Consistency Reliability

The reliability and validity of the measurement model were evaluated through reliability indicators, internal consistency reliability, convergent validity, and discriminant validity. The results of outer loading are presented in Table 4. In general, most constructs exhibit adequate internal consistency, with Cronbach's Alpha and Composite Reliability values exceeding the recommended threshold (>0.70). In particular, *the AI constructs Literacy, Behavioral Engagement, Cognitive Engagement, Critical Thinking, and Logical Reasoning* show a strong level of reliability, which indicates that the indicators used are able to measure these constructs consistently.

**Tabel 4.** Reliability Coefficients (Cronbach's Alpha and Composite Reliability)

	Cronbach's Alpha	Composite Reliability	Remarks
AI Literacy	0,722	0,816	Valid
Behavior Engagement	0,840	0,894	Valid
Cognitive Engagement	0,876	0,915	Valid
Critical Thinking	0,867	0,909	Valid
Logical Reasoning	0,780	0,872	Valid

<b>Social Engagement</b>	<b>0,608</b>	<b>0,765</b>	-
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Source: Data Processed

Although the Social Engagement construct has a Cronbach's Alpha value slightly below the conventional limit ( $\alpha = 0.608$ ), the Composite Reliability value is still at an acceptable level ( $CR = 0.765$ ), so the indicator is still considered reliable in representing the construct. In the PLS-SEM methodology, Composite Reliability is often considered more appropriate than Cronbach's Alpha, especially in constructs with limited or heterogeneous indicators. Therefore, the reliability of the Social Engagement construct in this study is considered adequate to proceed to structural model analysis.

### **Convergent Validity**

Table 5 shows that most of the constructs, namely AI Literacy, Behavioral Engagement, Cognitive Engagement, Critical Thinking, and Logical Reasoning, have AVE values above 0.50, thus meeting the convergent validity criteria. Although some indicators with loads below 0.60 were tested for removal, this step did not significantly increase the value of Composite Reliability or AVE. Therefore, as per the recommendations of the PLS-SEM literature, the measurement model in this study is still considered adequate for further analysis.

**Table 5.** Average Variance Extracted (AVE)

<b>Average Variance Extracted (AVE)</b>	
<b>AI Literacy</b>	0,528
<b>Behavior Engagement</b>	0,680
<b>Cognitive Engagement</b>	0,729
<b>Critical Thinking</b>	0,714
<b>Logical Reasoning</b>	0,694
<b>Social Engagement</b>	0,450

Source: Data Processed

The AVE value for the Social Engagement construct (0.450) is slightly below the conventional threshold, but it is still acceptable because the Composite Reliability value exceeds 0.60 ( $CR = 0.765$ ). This shows that although the variance described by the indicator is relatively moderate, the construct is still reliable and theoretically meaningful. Lower AVE scores may also reflect the characteristics of AI literacy learning that emphasize more individual interaction with AI systems than social collaboration, so the Social Engagement construct is still considered adequate for exploratory analysis in the context of AI literacy research.

### **Discriminant Validity**

Table 6 presents the value of the *Heterotrait Monotrait ratio* (HTMT) which is used to assess the discriminant validity between latent constructs. The results of the analysis showed that the entire HTMT value was below the conservative threshold of 0.90, which

indicates that each construct has clear empirical differences as well as represents a different conceptual domain. Thus, these findings confirm that the measurement model has met the criteria for discriminant validity as recommended in the literature on *structural equation modeling* methodology based on *partial least squares* (Henseler et al., 2015; Sarstedt et al., 2021).

**Table 6.** HTMT Matrix (Discriminant Validity)

	<b>AI Literacy</b>	<b>Behavior Engagement</b>	<b>Cognitive Engagement</b>	<b>Critical Thinking</b>	<b>Logical Reasoning</b>
<b>AI Literacy</b>					
<b>Behavior Engagement</b>	0,780				
<b>Cognitive Engagement</b>	0,708	0,832			
<b>Critical Thinking</b>	0,581	0,781	0,864		
<b>Logical Reasoning</b>	0,675	0,781	0,876	0,871	
<b>Social Engagement</b>	0,664	0,715	0,748	0,733	0,701

Source: Data Processed

Most construct pairs show HTMT values below the threshold, indicating an adequate separation between AI Literacy, student engagement dimensions, and high-level cognitive outcomes. Although the HTMT value between Behavioral Engagement and Cognitive Engagement is relatively high (0.932), the value is still acceptable because the two constructs are theoretically interrelated but can still be empirically distinguished in technology-based learning research. Overall, the HTMT results support the discriminant validity of the measurement model and show that the constructs in this study represent different but interrelated dimensions.

## Structural Model Evaluation

### Path Coefficients and Hypothesis Testing

#### a. AI Literacy → Student Engagement

The results of the analysis show that *AI literacy* has a strong and statistically significant influence on all dimensions of *student engagement*. *AI literacy* had a positive effect on *behavioral engagement* ( $\beta = 0.658$ ;  $t = 21.450$ ;  $p < 0.001$ ), *cognitive engagement* ( $\beta = 0.640$ ;  $t = 24.143$ ;  $p < 0.001$ ), and *social engagement* ( $\beta = 0.494$ ;  $t = 11.606$ ;  $p < 0.001$ ). These findings suggest that students with higher levels of AI literacy tend to be more actively engaged in learning activities, invest greater cognitive effort, and participate more meaningfully in social interactions during the learning process. The large coefficient of pathways shows that *AI literacy* is the main driver of learning engagement, especially in shaping behavioral and cognitive dimensions. These results empirically confirm the theoretical assumption that understanding of AI concepts and applications can increase students' confidence and *agency* in interacting with learning environments supported by AI technology.

**b. Student Engagement → Critical Thinking**

The results of the analysis further show that all dimensions of *student engagement* make a significant contribution to students' critical thinking skills. *Cognitive engagement* showed the strongest influence on *critical thinking* ( $\beta = 0.539$ ;  $t = 9.745$ ;  $p < 0.001$ ), followed by *student engagement* ( $\beta = 0.167$ ;  $t = 3.678$ ;  $p < 0.001$ ) and *behavioral engagement* ( $\beta = 0.149$ ;  $t = 2.486$ ;  $p = 0.013$ ). This pattern confirms the central role of cognitive engagement such as deep processing, reflection, and the use of learning strategies in fostering the development of higher-level thinking skills. Although *behavioral engagement* and *social engagement* show smaller effect sizes, their contributions remain significant, suggesting that active participation and collaborative interaction remain instrumental in supporting the critical analysis process. These findings are in line with various previous educational studies that emphasize that critical thinking abilities are primarily driven by deep cognitive investment, rather than just participation at a surface level.

**c. Student Engagement → Logical Reasoning**

A similar pattern was also found in the relationship between *student engagement* and *logical reasoning skills*. *Cognitive engagement* was again the strongest predictor ( $\beta = 0.546$ ;  $t = 10.036$ ;  $p < 0.001$ ), suggesting that sustained mental effort and analytical processing are important factors in the development of logical reasoning skills. Meanwhile, *social engagement* ( $\beta = 0.131$ ;  $t = 3.101$ ;  $p = 0.002$ ) and *behavioral engagement* ( $\beta = 0.136$ ;  $t = 2.626$ ;  $p = 0.009$ ) also showed significant positive effects, albeit with smaller effect sizes. Overall, these findings indicate that an AI-literacy-based learning environment that encourages cognitive challenges, discussion, and active engagement can contribute to improving students' logical reasoning skills. The structural relationship between constructs in this study was tested using *the bootstrapping procedure*, and the results of hypothesis testing are presented in Table 7.

**Tabel 7.** Path coefficients and hypothesis testing

	<b>Original Sample (O)</b>	<b>Sample Mean (M)</b>	<b>Standard Deviation (STDEV)</b>	<b>T Statistics ( O/STDEV )</b>	<b>P Values</b>
AI Literacy -> Behavior Engagement	0,658	0,658	0,031	21,450	0,000
AI Literacy -> Cognitive Engagement	0,640	0,642	0,027	24,143	0,000
AI Literacy -> Social Engagement	0,494	0,497	0,043	11,606	0,000
Behavior Engagement -> Critical Thinking	0,149	0,149	0,060	2,486	0,013
Behavior Engagement -> Logical Reasoning	0,136	0,134	0,052	2,626	0,009

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics ((O/STDEV))	P Values
Cognitive Engagement -> Critical Thinking	0,539	0,536	0,055	9,745	0,000
Cognitive Engagement -> Logical Reasoning	0,546	0,546	0,054	10,036	0,000
Social Engagement -> Critical Thinking	0,167	0,172	0,046	3,678	0,000
Social Engagement -> Logical Reasoning	0,131	0,135	0,042	3,101	0,002

Source: Data Processed

Overall, the structural model shows that *AI literacy* influences *critical thinking* and *logical reasoning* both directly and indirectly through various *student engagement* pathways, indicating a partial mediation effect. Among the three dimensions of engagement, *cognitive engagement* emerged as the most dominant mediation mechanism. These findings place *student engagement* especially the cognitive dimension as an important explanatory link between AI literacy and the development of students' high-level cognitive abilities.

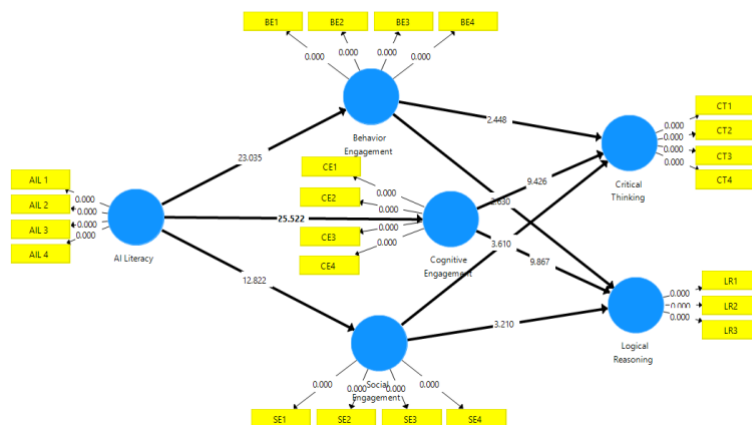


Figure 2. Structural Model Results (SmartPLS Output)

### Coefficient of Determination (R<sup>2</sup>)

Table 8 presents the coefficient of determination (R<sup>2</sup>) values for the endogenous constructs, indicating the explanatory power of the proposed structural model. The results show that AI literacy explains a substantial proportion of variance in Behavioral Engagement (R<sup>2</sup> = 0.433) and Cognitive Engagement (R<sup>2</sup> = 0.410), suggesting that students' level of AI literacy plays a significant role in shaping their engagement behaviors and cognitive involvement in AI literacy courses. These values can be interpreted as moderate explanatory power, which is acceptable and meaningful in educational and behavioral research contexts.

**Table 8.** Coefficient of Determination (R<sup>2</sup>)

	R Square	R Square Adjusted
<b>Behavior Engagement</b>	0,433	0,432
<b>Cognitive Engagement</b>	0,410	0,408
<b>Critical Thinking</b>	0,602	0,599
<b>Logical Reasoning</b>	0,556	0,553
<b>Social Engagement</b>	0,244	0,242

Source: Data Processed

The research model showed a strong explanatory ability to high-level cognitive outcomes. *Critical Thinking* has an R<sup>2</sup> value of 0.602 and *Logical Reasoning* of 0.556, which suggests that most of the variance of the two abilities can be explained by *behavioral engagement*, *cognitive engagement*, and *social engagement*. These findings confirm the important role of *student engagement* as a mediation mechanism that links *AI literacy* with the development of high-level cognitive abilities.

In contrast, the R<sup>2</sup> value in *Social Engagement* was relatively lower (R<sup>2</sup> = 0.244), indicating that *AI literacy* only partially explains the variance of students' social interactions in an AI-based learning environment. This is likely to reflect the characteristics of AI-based learning that are more individualized. Overall, the R<sup>2</sup> value indicates that the model has adequate to strong explanatory power, especially in explaining students' critical thinking and logical reasoning skills.

### Effect Size (f<sup>2</sup>)

*AI Literacy* in table 9 shows a large effect measure on *Behavioral Engagement* (f<sup>2</sup> = 0.765) and *Cognitive Engagement* (f<sup>2</sup> = 0.693), indicating that AI literacy is a dominant factor in shaping students' behavioral participation and cognitive engagement in AI-based learning. In addition, *AI Literacy* also has a moderate to large influence on *Social Engagement* (f<sup>2</sup> = 0.322), which suggests that even though social interaction is not the main focus of AI-based learning, AI literacy still contributes meaningfully to students' social engagement in learning activities.

**Table 9.** Effect size (f<sup>2</sup>)

	AI Literacy	Behavior Engagement	Cognitive Engagement	Critical Thinking	Logical Reasoning	Social Engagement
AI Literacy		0,765	0,693			0,322
Behavior Engagement				0,020	0,015	
Cognitive Engagement				0,240	0,220	
Critical Thinking						
Logical Reasoning						

	AI Literacy	Behavior Engagement	Cognitive Engagement	Critical Thinking	Logical Reasoning	Social Engagement
Social Engagement				0,045	0,025	

Source: Data Processed

*Behavioral Engagement* had a small effect on *Critical Thinking* ( $f^2 = 0.020$ ) and *Logical Reasoning* ( $f^2 = 0.015$ ), suggesting that surface participation had only a limited impact on high-level thinking skills. In contrast, *Cognitive Engagement* showed a moderate influence on *Critical Thinking* ( $f^2 = 0.240$ ) and *Logical Reasoning* ( $f^2 = 0.220$ ), confirming its role as a major factor in driving deep cognitive processing and analytical reasoning abilities. Meanwhile, *Social Engagement* had a small influence on both abilities ( $f^2 = 0.045$  and  $f^2 = 0.025$ ), suggesting that social interaction served as a supporting factor. Overall, these results confirm that *AI Literacy* builds student engagement, while *Cognitive Engagement* is the most powerful path in improving *critical thinking* and *logical reasoning*.

**Direct Effect**

AI literacy has a significant direct influence on higher-order thinking skills, namely critical thinking and logical reasoning. In particular, AI literacy had a significant effect on critical thinking ( $\beta = 0.526$ ,  $t = 19.235$ ,  $p < 0.001$ ), which suggests that the higher the AI literacy of students, the better their ability to analyze information, evaluate arguments, and make evidence-based decisions. In addition, AI literacy also has a significant positive influence on logical reasoning ( $\beta = 0.504$ ,  $t = 16.374$ ,  $p < 0.001$ ), which indicates that understanding and using AI technology can help students develop logical reasoning skills, such as identifying patterns, drawing conclusions, and structuring arguments systematically.

**Table 10.** Direct Effect

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics ( O/STDEV )	P Values
AI Literacy -> Critical Thinking	0.526	0.529	0.027	19.235	0.000
AI Literacy-> Logical Reasoning	0.504	0.510	0.031	16.374	0.000

Source: Data Processed

**Mediation Analysis**

Indirect effect analysis using *the bootstrapping* method showed that *AI literacy* affects *higher-order thinking skills* through *student engagement*. The results showed that all mediation pathways were statistically significant. *Behavioral engagement* mediated the relationship between *AI literacy* and *critical thinking* ( $\beta = 0.098$ ,  $p = 0.015$ ), *cognitive engagement* showed the strongest mediating effect ( $\beta = 0.345$ ,  $p < 0.001$ ), and *social engagement* also played a significant role ( $\beta = 0.083$ ,  $p < 0.001$ ). These findings show

that increasing AI literacy can strengthen students' *critical thinking* skills through increasing their involvement in the learning process.

**Table 11.** Indirect Effects (Mediation Analysis)

	<b>Original Sample (O)</b>	<b>Sample Mean (M)</b>	<b>Standard Deviation (STDEV)</b>	<b>T Statistics ( O/STDEV )</b>	<b>P Values</b>
AI Literacy -> Behavior Engagement -> Critical Thinking	0.098	0.097	0.040	2.439	0.015
AI Literacy -> Cognitive Engagement -> Critical Thinking	0.345	0.346	0.040	8.586	0.000
AI Literacy -> Social Engagement -> Critical Thinking	0.083	0.086	0.022	3.724	0.000
AI Literacy -> Behavioral Engagement -> Logical Reasoning	0.090	0.089	0.036	2.478	0.014
AI Literacy -> Cognitive Engagement -> Logical Reasoning	0.349	0.353	0.041	8.605	0.000
AI Literacy -> Social Engagement -> Logical Reasoning	0.065	0.068	0.023	2.799	0.005

Source: Data Processed

The results of mediation also showed a significant indirect influence of *AI literacy* on *logical reasoning* through three dimensions of *student engagement*. *Behavioral engagement* mediated the relationship significantly ( $\beta = 0.090$ ,  $p = 0.014$ ), while *cognitive engagement* again showed the strongest mediating effect ( $\beta = 0.349$ ,  $p < 0.001$ ), which confirms the importance of deep cognitive engagement in strengthening students' reasoning skills. In addition, *social engagement* also plays a significant role as a mediator

( $\beta = 0.065$ ,  $p = 0.005$ ). Overall, these findings confirm that *student engagement* is an important mechanism that explains how *AI literacy* contributes to the development of *higher-order thinking skills*, especially *critical thinking* and *logical reasoning*.

**Predictive Relevance**

The results of the analysis in table 11 show that all endogenous constructs have a positive  $Q^2$  value, which indicates that the proposed model has adequate *predictive relevance*. *Behavioral Engagement* ( $Q^2 = 0.287$ ) and *Cognitive Engagement* ( $Q^2 = 0.295$ ) showed a moderate level of *predictive relevance*, indicating that *AI literacy* is able to meaningfully predict student engagement patterns in AI literacy learning. These findings reinforce the role of *AI literacy* as a key factor influencing *student engagement* in technology-based learning environments.

**Tabel 11.** Predictive relevance ( $Q^2$ )

	SSO	SSE	$Q^2 (=1-SSE/SSO)$
<b>AI Literacy</b>	1.748.000	1.748.000	
<b>Behavior Engagement</b>	1.748.000	1.246.363	0.287
<b>Cognitive Engagement</b>	1.748.000	1.232.167	0.295
<b>Critical Thinking</b>	1.748.000	1.012.005	0.421
<b>Logical Reasoning</b>	1.311.000	821.080	0.374
<b>Social Engagement</b>	1.748.000	1.565.659	0.104

Source: Data Processed

The model also shows a strong *predictive relevance* to high-level cognitive ability. *Critical Thinking* has the highest  $Q^2$  value (0.421), followed by *Logical Reasoning* (0.374), which shows that student engagement-based pathways are effective in predicting the development of students' cognitive abilities. In contrast, *Social Engagement* has a lower  $Q^2$  value (0.104), which reflects a more limited but still relevant predictive role. Overall, the  $Q^2$  results confirm that structural models have adequate predictive capabilities, especially in explaining *critical thinking* and *logical reasoning*.

**Discussion**

**AI Literacy → Behavioral, Cognitive, and Social Engagement**

The test results showed that *AI literacy* had a strong and significant effect on *behavioral engagement* ( $\beta = 0.658$ ), *cognitive engagement* ( $\beta = 0.640$ ), and *social engagement* ( $\beta = 0.494$ ). These findings confirm that AI literacy is not just a technical competence, but also serves as an *enabling capability* that shapes the way students interact, think, and collaborate in a digital learning environment (Long & Magerko, 2020). Students who have an adequate understanding of AI tend to be more actively involved in learning activities, more reflective in information processing, and more confident in technology-based social interactions, which is in line with the findings of previous studies on the positive relationship between AI literacy, *self-efficacy*, and

learning engagement (Kong et al., 2022). In addition, AI literacy has been shown to increase *the sense of control* and *perceived usefulness* of learning technology, which in turn strengthens students' active participation in AI-based learning processes (Kong et al., 2022). Critically, the magnitude of *the effect size* ( $f^2 > 0.32$ ) suggests that AI literacy is not just a complementary variable, but rather a significant structural determinant in shaping student engagement, confirming its central role in the AI-mediated learning ecosystem (Long & Magerko, 2020)

### **Behavioral Engagement → Critical Thinking and Logical Reasoning**

The effect of *behavioral engagement* on *critical thinking* ( $\beta = 0.149$ ) and *logical reasoning* ( $\beta = 0.136$ ) was identified as significant but small in size ( $f^2 < 0.02$ ). This indicates that behavioral engagements such as attendance, participation, and task completion are not sufficient independently to encourage high-level thinking skills. These findings are in line with the classic criticism in the educational literature that *activity without cognition does not guarantee thinking* (Chi & Wylie, 2014), and is reinforced by recent studies emphasizing that behavioral engagement only serves as an initial prerequisite, not a primary driver of complex cognitive abilities (Deng et al., 2022; Fredricks et al., 2020). In other words, students can look "busy" in terms of activities without really engaging in the process of deep thinking.

### **Cognitive Engagement → Critical Thinking and Logical Reasoning**

*Cognitive engagement* showed the most dominant influence on *critical thinking* ( $\beta = 0.539$ ) and *logical reasoning* ( $\beta = 0.546$ ), with moderate to large *effect sizes* ( $f^2 \approx 0.22$ – $0.24$ ). These findings confirm that deep cognitive processes such as reflection, elaboration, and metacognition are the main mechanisms that transform the use of AI into higher-level thinking skills. These results are in line with research over the past five years that places *cognitive engagement* as a key mediator between the use of smart technology and *higher-order thinking skills* (Kohnke et al., 2023; Zhai et al., 2021). In this context, AI functions effectively only when it is used to *think with* students, not *thinking for* the learner.

### **Social Engagement → Critical Thinking and Logical Reasoning**

*Social engagement* had a significant effect on *critical thinking* ( $\beta = 0.167$ ) and *logical reasoning* ( $\beta = 0.131$ ), even with a small *effect size*. This suggests that social interactions such as discussion, collaboration, and exchange of ideas make cognitive contributions, but are supportive, not central. These findings reinforce the view that AI-based learning still requires a social dimension to avoid cognitive isolation, with an emphasis that the quality of interactions is more decisive than the quantity (Lim et al., 2023). In other words, discussions without a clear cognitive structure do not automatically improve students' reasoning abilities.

### **Practical Implications and Policy Recommendations**

Practically, the results of this study have direct implications for education policy and curriculum design. First, the integration of AI literacy in college curricula should not stop at the operational or ethical aspects of AI, but should be designed to explicitly stimulate cognitive engagement through reflective assignments, problem-based learning, and reasoning-based evaluation. Second, education policy needs to shift the focus from just adopting AI technology to strengthening the pedagogic capacity of lecturers in designing learning activities that force students to think critically and logically with the help of AI. Without proper pedagogical design, AI risks lowering cognitive depth instead of improving it. Third, the AI literacy curriculum should be designed in a spiral and contextual manner, including: 1) conceptual understanding of AI; 2) the use of AI for exploration and analysis, and 3) critical reflection on AI output. This approach ensures that AI functions as *a cognitive amplifier*, not a *cognitive shortcut*.

## CONCLUSION

This study demonstrates that AI literacy plays an important role in developing students' higher-order thinking skills, particularly critical thinking and logical reasoning. The findings show that AI literacy significantly influences students' behavioral, cognitive, and social engagement, which in turn contribute to the improvement of higher-order cognitive abilities. Among the three dimensions, cognitive engagement provides the strongest contribution, indicating that deeper intellectual involvement in learning activities is crucial for developing advanced reasoning skills. In addition, AI literacy also has a direct and significant effect on both critical thinking and logical reasoning. Overall, these findings highlight that strengthening AI literacy and promoting active student engagement are essential strategies for supporting the development of higher-order thinking in higher education.

## REFERENCES

- Andrian, H., Putra, D., & Wijaya, T. (2025). AI in Higher Education: Enhancing Cognitive Skills and Risks of Cognitive Offloading. *Journal of Science Learning and Technology*, 15(3), 45–62. <https://journal.unesa.ac.id/index.php/jslt/article/view/46867>
- Appleton, J. J., Christenson, S. L., Kim, D., & Reschly, A. L. (2008). Measuring Cognitive and Psychological Engagement: Validation of the Student Engagement Instrument. *Journal of School Psychology*, 46(5), 427–445. <https://doi.org/10.1016/j.jsp.2008.01.002>
- Bond, M., Bedenlier, S., Mar'in, V. I., & H"andel, M. (2020). Digital Education: Student Engagement in Technology-Enhanced Learning Environments. *Computers & Education*, 145, 103729. <https://doi.org/10.1016/j.compedu.2019.103729>
- Chan, K. (2026). *Artificial Intelligence as a Cognitive Partner in Higher Education*. <https://arxiv.org/abs/2602.15638>
- Chi, M. T. H., & Wylie, R. (2014). The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes. *Educational Psychologist*, 49(4), 219–243. <https://doi.org/10.1080/00461520.2014.965823>

- Chiu, T. K. F. (2025). AI Literacy and Competency: Definitions, Frameworks, Opportunities, and Challenges. *Computers & Education*. <https://doi.org/10.1080/10494820.2025.2514372>
- Deng, F., Tondeur, J., & Yu, Y. (2022). Behavioral Engagement and Learning Outcomes in Technology-Enhanced Learning Environments. *Computers & Education*, 187, 104569. <https://doi.org/10.1016/j.compedu.2022.104569>
- Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School Engagement: Potential of the Concept, State of the Evidence. *Review of Educational Research*, 74(1), 59–109. <https://doi.org/10.3102/00346543074001059>
- Fredricks, J. A., Filsecker, M., & Lawson, M. A. (2020). Student Engagement and Its Relation to Academic Achievement: A Meta-Analysis. *Educational Psychology Review*, 32(1), 1–45. <https://doi.org/10.1007/s10648-019-09468-1>
- Hair, J., & Alamer, A. (2022). Partial Least Squares Structural Equation Modeling (PLS-SEM) in second language and education research: Guidelines using an applied example. *Research Methods in Applied Linguistics*, 1(3). <https://doi.org/10.1016/j.rmal.2022.100027>
- Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science*, 43(1), 115–135. <https://doi.org/10.1007/s11747-014-0403-8>
- Immanuella, B. D. U. (2023). Student engagement among undergraduate learners. . *Journal of Interdisciplinary Education and Research*.
- Kohnke, L., Hofer, S. I., & Rienties, B. (2023). Exploring the Role of Cognitive Engagement in AI-Mediated Learning Environments. *British Journal of Educational Technology*, 54(2), 412–429. <https://doi.org/10.1111/bjet.13245>
- Kong, S. C., Wong, H., & Chen, X. (2022). Artificial Intelligence Literacy and Student Engagement in Technology-Enhanced Learning Environments. *Computers & Education*, 187, 104546. <https://doi.org/10.1016/j.compedu.2022.104546>
- Kuhn, D. (2000). Metacognitive Development. *Current Directions in Psychological Science*, 9(5), 178–181. <https://doi.org/10.1111/1467-8721.00088>
- Lim, C., Kim, H., & Kim, J. (2023). Social Engagement and Cognitive Outcomes in AI-Supported Learning Environments. *Computers & Education*, 196, 104689. <https://doi.org/10.1016/j.compedu.2023.104689>
- Long, D., & Magerko, B. (2020). What is AI Literacy? Competencies and Design Considerations. *Conference on Human Factors in Computing Systems - Proceedings*. <https://doi.org/10.1145/3313831.3376727>
- Lu, K., Zhu, J., Pang, F., & Shadiev, R. (2025). Understanding the relationship between colleges students' artificial intelligence literacy and higher order thinking skills using the 3P model: the mediating roles of behavioral engagement and peer interaction. *Educational Technology Research and Development*, 73(2). <https://doi.org/10.1007/s11423-024-10434-1>
- Qadeer, A. (2025). The Mediating Impact of Student Engagement on the Association between Generative AI-Based Feedback and Academic Performance in Higher Education. *Journal of Research, Innovation, and Strategies for Education (RISE)*, 2(1). <https://doi.org/10.70148/rise.18>
- Salido, A., Syarif, I., Suparjan, Wana, P. R., Sitepu, M. S., & Melisa, R. (2025). Mapping the Landscape of Critical Thinking Skills in Higher Education in the AI Era: A

- Bibliometric and Systematic Literature Review. *Journal of Culture and Values in Education*, 8(2). <https://doi.org/10.46303/jcve.2025.23>
- Sari, D. K., Supahar, S., Rosana, D., Dinata, P. A. C., & Istiqlal, M. (2025). Measuring artificial intelligence literacy: The perspective of Indonesian higher education students. *Journal of Pedagogical Research*. <https://doi.org/10.33902/JPR.202531879>
- Sarstedt, M., Ringle, C. M., & Hair, J. F. (2021). Partial Least Squares Structural Equation Modeling. In *Handbook of Market Research*. [https://doi.org/10.1007/978-3-319-57413-4\\_15](https://doi.org/10.1007/978-3-319-57413-4_15)
- Yilmaz Soylu, M., Lee, J., Hung, J. T., Cui, C. Z., & Joyner, D. (2025). AI literacy as a key driver of user experience in AI-powered assessment: insights from Socratic mind. *Interactive Learning Environments*. <https://doi.org/10.1080/10494820.2025.2564739>
- Zhai, X., Zhang, H., & Chen, X. (2021). Cognitive Engagement as a Mediator in Technology-Enhanced Higher-Order Learning. *Computers & Education*, 167, 104190. <https://doi.org/10.1016/j.compedu.2021.104190>
- Zhan, Y. (2022). Developing and validating a student feedback literacy scale. *Assessment and Evaluation in Higher Education*, 47(7). <https://doi.org/10.1080/02602938.2021.2001430>