I.J. Modern Education and Computer Science, **2026, 4, 40-58**
Published Online on August 8, 2026 by MECS Press (http://www.mecs-press.org/)
DOI: 10.5815/ijmecs.2026.04.03

Augmented Reality (AR) and Gamification on Immersive Learning Experiences and Perceived Academic Performance: Using SEM and Network Analysis

Hendra Hidayat*
Universitas Negeri Padang/Department of Electronic Engineering Education, Padang, 25131, Indonesia
E-mail: hendra.hidayat@ft.unp.ac.id
ORCID iD: https://orcid.org/0000-0002-4669-1252
*Corresponding author

Dewi Artati Padmo Putri
Universitas Terbuka/Department of Educational Technology, Tangerang Selatan, 15437, Indonesia
E-mail: dewi@ecampus.ut.ac.id
ORCID iD: https://orcid.org/0000-0002-7358-5519

Wahyu Sakti Gunawan Irianto
Universitas Negeri Malang/Department of Electrical Engineering, Malang, 65145, Indonesia
E-mail: wahyu.sakti.ft@um.ac.id
ORCID iD: https://orcid.org/0009-0002-5609-4045

Putrinda Inayatul Maula
Universitas Negeri Malang/Department of Electrical Engineering, Malang, 65145, Indonesia
E-mail: putrinda.inayatul.ft@um.ac.id
ORCID iD: https://orcid.org/0009-0009-4553-7155

Diki Diki
Universitas Terbuka/Department of Statistics, Tangerang Selatan, 15437, Indonesia
E-mail: dikinian@ecampus.ut.ac.id
ORCID iD: https://orcid.org/0000-0002-2419-7093

Received: June 23, 2025; Revised: September 16, 2025; Accepted: January 10, 2026; Published: August 8, 2026

Abstract: This study examines how critical thinking skills influence the relationship among cognitive load, self-efficacy, and problem-solving abilities in the context of immersive learning experiences and perceived academic performance among college students in technical education programs. Emerging technologies such as augmented reality (AR) and gamification were employed in this study to enhance student engagement and cognitive function. A quantitative approach was employed to gather data from 748 Indonesian college students enrolled in technical education programs. The study employed structural equation modeling (SEM) via SmartPLS 4.0 to examine direct, indirect, and moderating effects. Digital literacy was examined as a moderating variable in the model. The results indicate that critical thinking significantly influences the relationship between cognitive load, self-efficacy, and problem-solving skills in facilitating meaningful learning and academic success. Problem-solving ability was the most significant predictor of critical thinking. Notably, digital literacy exerted a negative moderating influence on the relationship between critical thinking and immersive learning. This indicates that digital proficiency lacking cognitive regulation may hinder engagement in deep learning. The findings underscore the significance of cultivating critical thinking abilities within immersive and game-based learning contexts. Digital literacy programs ought to encompass more than mere technical competencies. Students should also be instructed in applying critical thinking to their knowledge acquisition and metacognitive processes. This research contributes to existing literature by demonstrating a novel approach to integrating cognitive-affective factors, critical thinking, and immersive learning experiences in Indonesian higher education. It emphasizes the significance of digital literacy and reiterates the importance of augmented reality and game-based learning in attaining essential educational objectives.

Index Terms: Augmented Reality (AR), Gamification, Perceived Academic Performance, Immersive Learning Experiences, Critical Thinking Skills

1. Introduction

The fourth industrial revolution and the swift digitalization of education compel colleges and universities, particularly those offering engineering programs, to adopt a more interactive, contextual, and adaptive learning methodology [1]. In this context, Augmented Reality (AR) and gamification are two pedagogical innovations that have been extensively studied for their potential to improve engineering student engagement and enable the tangible visualization of abstract technical concepts [2]. The efficacy of this technology integration is profoundly influenced by internal student factors, such as cognitive load, self-efficacy, and problem-solving ability—these three variables are crucial for cultivating critical thinking skills, essential for tackling technical challenges in real-world contexts [3].

Engineering students must confront challenging tasks such as engineering calculations, design simulations, and system analysis [4]. Cognitive load is pertinent here: poorly designed augmented reality can hinder students' retention of information, thereby impeding their comprehension of concepts [5]. In contrast, students with high self-efficacy are typically more confident in interacting with new media and performing technically demanding tasks [6]. Problem-solving skills, including identifying issues, devising solutions, and employing technical strategies, are fundamental competencies that students must acquire in engineering school prior to developing critical thinking skills [7].

In engineering, critical thinking skills encompass the application of logic, systematic evaluation of technical parameters, verification of solution efficacy, and contemplation of the design process [8]. Immersive learning experiences refer to the degree of "immersion" students perceive within an interactive technical learning environment [9]. Critical thinking serves as a mediating variable linking cognitive-affective factors to two primary outcomes: academic performance and immersive learning experience [10]. Critical thinking skills are predicated on the integration of cognitive and affective influences, resulting in two primary outcomes: Immersive Learning Experiences, characterized by deep and significant student engagement [3], and Academic Performance, evaluated through student grades and the quality of assignments [11].

This study contributes novel insights to the field of education by simultaneously examining four aspects: augmented reality technology, gamification elements, students' cognitive and emotional competencies, and their critical thinking skills alongside learning outcomes [11]. Nevertheless, there is a paucity of studies employing intricate models with multiple variables and path analysis to examine immersion and academic outcomes [10]. Moreover, few studies utilize cognitive load as a control variable, whereas a recent study [5] demonstrated that students' cognitive load profiles exhibit significant variability.

This study does not assert conceptual originality in the application of augmented reality, gamification, or structural equation modeling, as these methodologies have been extensively investigated in previous research. Its contribution is to offer an incremental and integrative validation of the structural relationships among cognitive-affective factors (cognitive load, self-efficacy, and problem-solving skills), immersive learning experiences, and perceived academic performance, mediated by critical thinking in augmented reality and gamification learning contexts. This study enhances existing SEM-based analyses by integrating network analysis as a supplementary exploratory method, facilitating the identification of indicator-level centrality patterns that emphasize critical thinking as a metacognitive connector rather than solely an outcome variable. The findings provide exploratory insight by demonstrating a small and negative moderating effect of digital literacy on immersive learning experiences, indicating that technical competency devoid of reflective cognitive regulation may not promote immersion. These contributions provide a contextually relevant and theoretically insightful viewpoint on immersive learning within Indonesian engineering education.

This study seeks to address several significant questions: What is the impact of cognitive load, self-efficacy, and problem-solving abilities on critical thinking skills in augmented reality and gamification-based learning environments?; To what extent do critical thinking skills influence Immersive Learning Experiences when considering the other three variables?; Can cognitive load, self-efficacy, or problem-solving skills lead to an immersive learning experience or high grades without prior development of critical thinking skills? This study provides a progressive addition by including cognitive-affective elements, critical thinking, immersive learning experiences, and perceived academic success in augmented reality and gamification-based engineering education settings. This research integrates SEM and network analysis to offer complementing structural and relational insights, in contrast to previous studies that mainly focus on isolated relationships. The exploratory discovery of a negative moderating effect of digital literacy underscores the necessity of synchronizing technology proficiency with introspective cognitive regulation.

2. Literature Review

2.1. Cognitive Load

Cognitive Load Theory is a fundamental concept in modern instructional design, especially in relation to advanced educational technologies such as Augmented Reality (AR) and gamification [12,13]. Cognitive Load Theory (CLT) [14] asserts that human memory possesses a limited working capacity, and an overwhelming cognitive load can obstruct efficient learning. Recent studies indicate that augmented reality (AR) can reduce extraneous cognitive load by providing direct visualizations that are seamlessly integrated with real objects [5]. This mitigates the divided attention effect, wherein learners must focus on multiple sources of information simultaneously [15].

The increasing integration of interactive technologies such as Augmented Reality (AR) and gamification in engineering education in Indonesian higher education, comprehending cognitive load is essential for enhancing students' critical thinking abilities [15]. Cognitive load refers to the extent of mental effort required by working memory during the acquisition of new knowledge [16]. When extraneous load is diminished and germane load is amplified, students exhibit an enhanced cognitive capacity to process information, evaluate solution options, and make informed decisions—fundamental components of critical thinking [16]. Therefore, in modern technology-driven instructional design, educators must account for content and media as well as the strategic management of students' cognitive load [17]. This implication is highly relevant to the development of 21st-century learning models focused on acquiring higher-order thinking skills [13].

H1: Cognitive load has a significant relationship with critical thinking skills

2.2. Self-Efficacy

Self-efficacy refers to an individual's confidence in their capacity to accomplish a task [18]. Self-efficacy is a significant predictor of students' engagement in learning, their perseverance, and [19]. Students with elevated self-efficacy tend to exhibit greater motivation in accomplishing challenging tasks, increased patience during setbacks, and a more proactive approach to managing their own education [20]. Self-efficacy is increasingly significant as learning technologies such as augmented reality and gamification gain popularity. This is due to students encountering complex and constantly evolving learning environments [21].

In the last decade, numerous researchers have investigated the correlation between self-efficacy and critical thinking ability [22]. Critical thinking necessitates the ability to analyze, synthesize, evaluate, and reflect, alongside a confidence to navigate intellectual ambiguity and complex information [23]. Numerous research studies indicate that students possessing high self-efficacy are more inclined to engage in discussions, formulate arguments, and thoughtfully evaluate ideas, all of which are essential components of critical thinking [22]. Gamification to enhance self-efficacy positively influenced problem-solving and reflective thinking, subsequently improving critical thinking skills [24]. Students are more inclined to engage in learning when they possess confidence in their own capabilities [21]. This additionally aids them in developing logical, analytical, and independent thinking skills. This implication underscores the necessity for educators to design learning interventions that not only impart knowledge but also enhance students' self-esteem, thereby facilitating the continuous development of their critical thinking abilities.

H2: Self-efficacy shows a significant relationship with critical thinking skills

2.3. Problem-Solving Skill

Problem-solving skills are crucial for students to address academic and professional challenges in the 21st century; this ability involves a systematic cognitive process that includes problem identification, situational analysis, the development of alternative solutions, and the implementation and evaluation of decisions [25]. In higher education, especially within engineering and science fields, students are required to tackle open-ended problems that do not have a definitive solution, demanding adaptable, innovative, and rational thinking [26]. Thus, the enhancement of problem-solving skills is the principal aim in the formulation of a competency-based curriculum [27].

The relationship between problem-solving capabilities and critical thinking skills is robust and reciprocal [28]. Critical thinking is a cognitive framework that allows students to evaluate information, compare alternatives, and make decisions based on rational evidence, all of which are essential to problem-solving [29]. Empirical research demonstrates that improving problem-solving skills directly promotes the advancement of critical thinking abilities, especially in problem-based learning and technological simulations such as augmented reality [30]. Complex problem-solving requires students to identify technical solutions while also reflecting on their cognitive processes, a crucial element of critical thinking [28]. Furthermore, critical thinking abilities augment the effectiveness of problem-solving techniques [26,27]. Students demonstrating advanced critical thinking abilities are typically more proficient in choosing appropriate strategies, avoiding cognitive biases, and assessing the consequences of their choices.

H3: Problem-solving skills show a significant relationship with critical thinking skills

2.4. Critical Thinking Skill

Critical thinking skills exhibit students' capacity to objectively assess facts and arguments, recognize assumptions, and make reasoned decisions in higher education [31]. Critical thinking skills serve as the most reliable indicator of a student's preparedness for academic and professional challenges as the volume and complexity of information increase [32]. In technology-enhanced education, this competency is associated with advanced cognitive processes and the initiation of profound learning experiences [33].

Immersive learning experiences have arisen with the advent of new educational technologies such as virtual reality and augmented reality [34]. Students are physically and mentally engaged in realistic simulations; those who effectively integrate new information with existing knowledge, pose reflective enquiries, and critically assess situations derive the greatest advantages from immersive learning [35]. Critical thinking enables the assessment of immersive learning experiences. Immersive learning environments such as engineering simulations, augmented reality laboratories, and challenge-based educational games are complex, compelling students to engage in reflective, flexible, and empirical thinking [36]. Critical thinking enables students to maneuver through a demanding educational landscape and converts information into knowledge [37]. Immersive technology in higher education must be harmonized with critical thinking methodologies. Learning is profound, beneficial, and enduring, transcending mere visual or interactive engagement. In higher education literature, critical thinking skills are acknowledged as a crucial determinant of academic success [38]. Critical thinking demonstrates students' ability to analyze information, evaluate arguments, make data-driven decisions, and formulate logical and rational solutions [3]. These constitute essential components of academic assignments that necessitate more than mere memorization of facts.

2.5. Immersive Learning Experiences

Immersive Learning Experiences engage students in a digitally simulated environment that resembles the real world. This enables them to concurrently engage all their senses, emotions, and thoughts [39]. Learning is made more interactive and relevant with VR, AR, and simulation-based learning. Immersive learning has demonstrated enhancements in motivation, comprehension, and memory [40]. Its advantages include facilitating students' comprehension of abstract concepts, offering experiential learning opportunities, and promoting self-reflection.

Immersive learning is most effective with intelligent, analytical students. Critical thinkers can evaluate a situation, recognize the issue, and discover innovative methods of learning in an immersive context [41,42]. Critical thinking skills facilitate active learning for students in an immersive environment. Critical thinkers will more readily acquire new knowledge, integrate it with existing understanding, and comprehend the impact of their learning decisions in immersive environments such as augmented reality laboratories or technical simulations [43]. Critical thinking skills are vital for experiential learning and the application of new technology in education [44]. Incorporating critical thinking into immersive learning designs enhances the appeal and utility of technology.

H4: Critical thinking skills show a significant relationship with immersive learning experiences

2.6. Perceived Academic Performance

Perceived academic performance is the principal criterion employed to assess the success of students in higher education; this accomplishment is generally demonstrated through the fulfilment of assignments, elevated grades, and examination results that reflect a high degree of proficiency in the subject, practical skills, and advanced cognitive abilities [45]. Perceived academic performance is now assessed not only by numerical metrics but also by students' ability to understand and perform complex tasks in diverse contexts, as competency-based learning and critical thinking gain prominence in educational institutions [46]. Consequently, in the contemporary age of digital and interactive education, academic achievement is affected by elements beyond cognitive engagement. It is also affected by the ability to learn autonomously and metacognitive skills [47].

Students who excel in critical thinking typically compose essays filled with compelling arguments, solve mathematical problems methodically, and achieve superior results on performance assessments and project-based learning [48]. Moreover, critical thinking enhances the understanding of concepts and enables the swift, autonomous, and efficient application of knowledge in unfamiliar situations. These factors directly enhance perceived academic performance [49]. Students can understand intricate situations, make decisions amidst uncertainty, and independently reflect on their acquired knowledge when utilizing technology for learning, such as immersive learning and simulations [50]. Critical thinking constitutes an invaluable competency. Consequently, a sustainable approach to improving academic performance in higher education is the implementation of active learning strategies, formative assessments, and problem-solving tasks to foster students' critical thinking abilities.

H5: Critical thinking skills show a significant relationship with perceived academic performance

2.7. Digital Literacy

Currently, digital literacy encompasses more than merely understanding how to utilize technology; it also encompasses students' proficiency in utilizing digital information responsibly and critically when accessing, evaluating, creating, and communicating with others [31]. The three primary components of digital literacy are technical, cognitive, and socio-emotional [51,52]. All these components collaborate to facilitate students' engagement with digital learning environments in a deliberate and dynamic manner [53]. In the realm of immersive and interactive digital learning, students with higher digital literacy typically exhibit greater cognitive flexibility when utilizing technology for critical thinking and problem-solving [54].

Digital literacy is essential to proficiently utilize technology to effectively balance the demands of critical thinking and profound learning [55]. To maximize the benefits of simulation-based learning, whether through virtual reality (VR) or augmented reality (AR), students must possess proficient technological skills [56]. Students lacking proficiency in digital literacy may struggle with complex digital platforms, hindering their cognitive engagement in immersive environments, despite their strong critical thinking skills [57,58]. Conversely, students with advanced digital literacy can independently navigate digital content, engage in profound reflection on their educational experiences, and comprehend learning contexts in a manner that holds greater significance for them [59]. Digital literacy must be integrated into higher education curricula to enable students to fully harness the advantages of critical thinking skills, resulting in excellent grades and transformative learning experiences.

H6: Digital literacy has a significant moderating effect on the relationship between critical thinking skills and immersive learning experiences

Mastering technology is crucial for enhancing the connection between critical thinking and academic success [60]. A robust correlation exists between critical thinking and students' perceived academic performance, particularly in project-based tasks and reflective evaluations [61]. Due to the constant evolution of technology, students must learn to utilize it to enhance their cognitive abilities [62,63]. Students possessing high digital literacy can effectively utilize digital learning resources to formulate robust arguments, critically assess sources with appropriate scepticism, and efficiently accomplish challenging academic tasks [64]. Consequently, digital literacy enhances the efficacy of critical thinking in augmenting perceived academic performance, particularly in online and technology-driven education.

H7: Digital literacy has a significant moderating effect on the relationship between critical thinking skills and perceived academic performance

3. Methodology

This study uses a quantitative approach to gather and analyze data about students in engineering education in Indonesian higher education. Due to the large population of students, convenience sampling was used to select participants, making the process easier but less rigorous. It is important to have an adequate sample size, as a small sample might not represent the entire population accurately and [65]. This study utilized a convenience sampling method to recruit participants with direct experience in augmented reality (AR) and gamification-based learning applications. Convenience sampling was employed due to the contextual and technological specificity of the study, as only students with prior experience in AR- and gamification-supported instructional media were qualified to offer significant responses. Random sampling from the wider student population would likely have incorporated participants lacking adequate experience with these technologies, thus introducing measurement noise and diminishing construct validity. Despite the potential for selection bias, convenience sampling is frequently utilized in exploratory research and technology-enhanced learning studies, particularly when access to specialized learning environments is limited. To address this limitation, the study utilized a substantial sample size (n = 748), multiple institutions, and rigorous analytical methods (PLS-SEM and network analysis) focused on identifying consistent relational patterns rather than population estimates. The findings are thus interpreted as context-specific correlations within Indonesian engineering education rather than universal causal relationships. This study focuses on engineering education techniques in Indonesian higher education that utilize AR and gamification. Students who have used AR and gamification applications were invited to complete the questionnaire. Examples of the applications used are shown in Fig. 1.

Fig. 1 shows the augmented reality and gamification applications used in this study. Augmented Reality (AR): Each topic on passive and active components is equipped with 3D visualization using AR. Users can view 3D models of electronic components in detail, interact with the models to understand their internal structure, how they work, and how they are installed in real circuits. This AR feature allows students to gain a more concrete and visual understanding of the components they are studying.

Quizzes and Gamification: To test students' understanding, this application is equipped with an interesting gamification-based quiz feature, with various question types, such as multiple-choice and interactive questions related to the characteristics, functions, and applications of passive and active components. Gamification in quizzes makes learning more interesting, for example through point or time mechanisms to increase learning motivation; Basic Electronic Component Puzzles: There are also puzzles designed based on the basic composition and function of electronic components. Students will be asked to assemble simple electronic circuits with the right components, providing logical and technical challenges that improve their analytical skills.

While augmented reality and gamification constitute the educational framework of this study, they were neither experimentally altered nor compared to control conditions. The findings should not be construed as proof of causal impacts of augmented reality or gamification on learning outcomes. The results indicate associations seen in AR- and gamification-based learning settings, where critical thinking and cognitive-affective factors engage with immersive learning experiences and perceived academic success. Future research utilizing experimental or quasi-experimental methodologies is necessary to delineate the distinct impacts of augmented reality and gamification in comparison to traditional teaching methods.

Therefore, the decision was made to use a Likert Scale as the assessment method in this study. Each measurement item was assigned a score ranging from 1 (strong disagreement) to 5 (strong agreement). The primary data collection tool in this experiment was questionnaires. This study used previous primary research assessment tools. Research variables are assessed by questionnaire. This questionnaire collects data on cognitive load, self-efficacy, problem-solving skill, critical thinking skill, digital literacy, immersive learning experiences and perceived academic performance.

To measure cognitive load, this study used an instrument comprising 7 items from a previous study by Buchner et al. (2022) [15]. The items represented cognitive load, such as “I can understand the material presented in AR or gamification applications without feeling overwhelmed” and “Tasks in AR or gamification-based learning are quite clear and not confusing.”

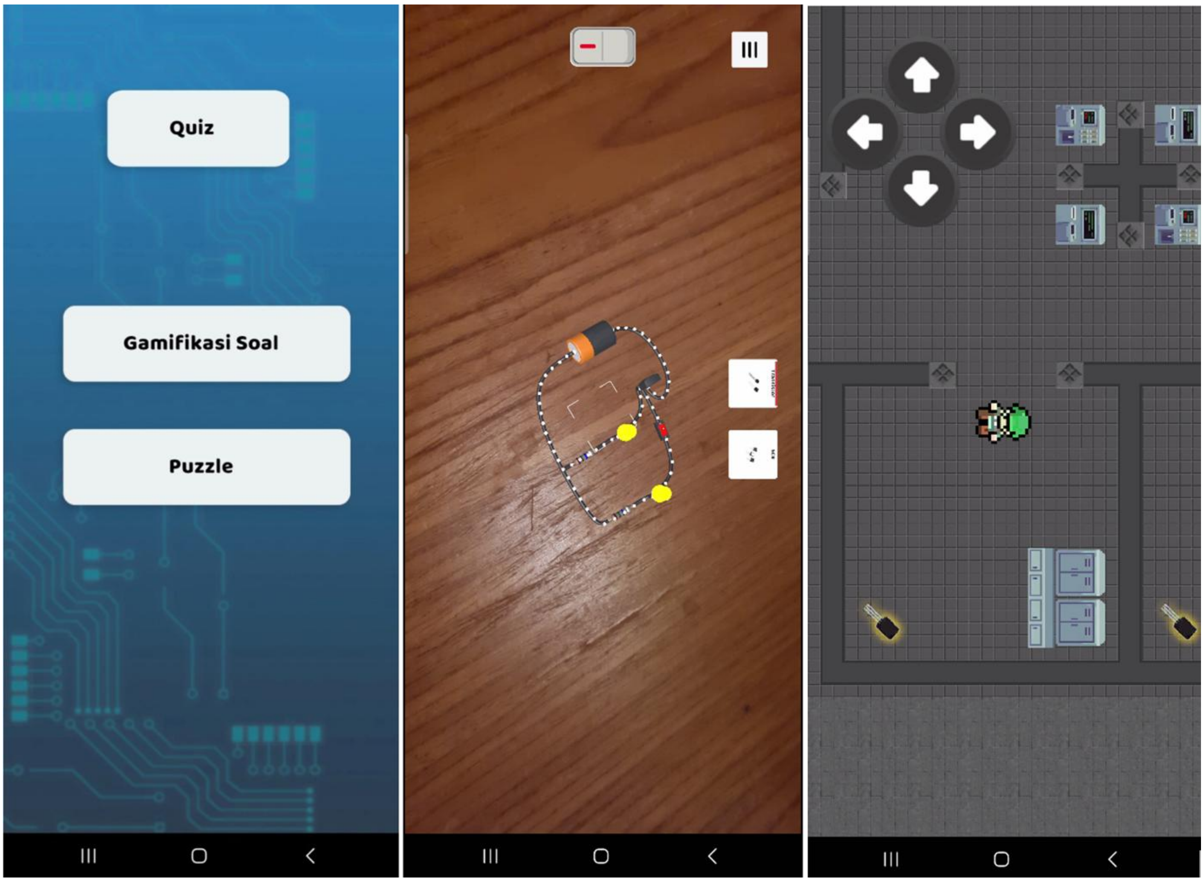

Fig. 1. Augmented Reality and Gamification Apps.

Furthermore, this study used an instrument to measure self-efficacy, comprising 7 items from Othman et al. (2024) [21]. The items represented self-efficacy, such as “I am confident in operating augmented reality and gamification-based learning devices and applications” and “I am confident in being able to complete tasks or challenges given through AR and gamification learning applications.”

Moreover, this study used an instrument to measure problem-solving skills, comprising 7 items from Cheng et al. (2024) [27]. The items included statements such as “I can recognize problems or challenges in AR or gamification-based learning activities” and “I am able to understand the essence of the problems presented in digital learning simulations or games.”

To measure critical thinking skills, this study adopted 7 items from a previous research study by Stenseth et al. (2025) [31]. The questions represented the learner's experience, such as “being able to quickly recognize problems that arise in AR-based learning simulations or games” and “being able to analyze the information or instructions available to understand the challenges in learning applications.”

To measure digital literacy, this study adopted 7 items from a previous research study by Nevrelova et al. (2024) [54]. The items represented students' digital literacy, such as “I can use augmented reality and gamification-based applications without difficulty” and “I am able to understand and access interactive features in AR-based learning applications or educational games.”

To measure immersive learning experiences, this study used 7 items from a previous study by Tursunova et al. (2024) [40]. The questions described students' feelings regarding immersive learning experiences, such as "feeling like they are really in the world of learning when using AR or gamification-based media" and "often forgetting the time when learning using AR or gamification applications because they really enjoy the process."

Finally, this study utilized a 7-item instrument to measure perceived academic performance, adapted from a previous study by Malhotra et al. (2023) [48]. Sample items included: "I found it easier to understand lesson concepts through visualizations and simulations displayed with augmented reality technology" and "My exam scores increased after using AR-based learning media and gamification."

This study used SmartPLS 4, a variation-based Partial Least Squares (PLS) SEM, to analyze data and create models. The first step was to test the measurement model's accuracy and consistency [66]. Second, convergent validity was assessed using Average Variance Extracted (AVE) and item loadings. We also performed network analysis on this study. Network analysis is an analytical approach used to study the structure and dynamics of relationships between entities (nodes) connected through ties (edges) in a network system [67]. This technique allows researchers to systematically describe, visualize, and measure complex social relationships, information, or organizational structures. The importance of network analysis in quantitative research also lies in its ability to combine relational data with advanced statistical analysis, such as network regression, social structure simulation, and graph-based longitudinal analysis. Network analysis was utilized as a supplementary exploratory technique to enhance the findings of structural equation modeling (SEM), rather than serving as an inferential or causal approach. SEM was employed to evaluate hypothesized relationships at the construct level, whereas network analysis was utilized to illustrate and analyze indicator-level interconnections and centrality patterns within the learning constructs. This method facilitates a more detailed examination of how particular indicators, especially those associated with critical thinking, serve as integrative components within the broader learning network. Consequently, network analysis is employed to enhance interpretation and corroborate findings, without supplanting or replicating the inferential function of SEM.

4. Results and Discussion

4.1. Structural Equation Modeling (SEM) Analysis

Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed for the analysis. This method is recommended for small samples or those with an uncertain or non-normal distribution [68]. Each construct was assessed for the quality of its measurement using Cronbach's alpha, Composite Reliability, Standardized Item Loadings, Average Variance Extracted (AVE), and Heterotrait-Monotrait Ratio of Correlations (HTMT).

Discriminant validity was assessed using the Heterotrait-Monotrait ratio of correlations (HTMT), as presented in Table 1. All HTMT values among constructs were below the 0.90 threshold, signifying that each construct in the model possesses sufficient conceptual differentiation from other constructs.

Table 1. Heterotrait-Monotrait Correlation Ratio (HTMT).

Variable	AP	CL	CriTS	DL	ILE	PSS	SE
AP							
CL	0.762						
CriTS	0.763	0.880					
DL	0.860	0.773	0.811				
ILE	0.763	0.870	0.857	0.735			
PSS	0.778	0.883	0.747	0.795	0.855		
SE	0.817	0.785	0.828	0.930	0.724	0.813	

According to Table 2, all Composite Reliability and Cronbach's alpha values exceed 0.70 [68]. Table 2 shows that the data meets the convergent validity requirements. The Average Variance Extracted (AVE) for each construct exceeds 0.50, and all factor loadings for each indicator on the relevant latent construct exceed 0.60.

Table 2. Cronbach's Alpha, Composite Reliability, Average Variance Extracted (AVE).

Variable	α	CR	AVE
AP	0.925	0.929	0.692
CL	0.942	0.943	0.742

CriTS	0.941	0.942	0.740
DL	0.932	0.933	0.709
ILE	0.919	0.927	0.675
PSS	0.939	0.940	0.733
SE	0.934	0.935	0.717

In PLS-SEM, hypothesis testing is performed to assess the relationships between constructs within the structural model. The test results are represented by the path coefficient, t-statistic, p-value, and confidence interval, derived using the bootstrapping method. A relationship between constructs is deemed significant if the t-statistic exceeds 1.96 (two-tailed, $\alpha = 0.05$), the p-value is less than 0.05, and the confidence interval excludes zero, as recommended by Hair et al. (2017) [68]. The path coefficient value signifies the direction and intensity of the relationship, whereas the R^2 value evaluates the model's predictive capacity concerning endogenous constructs. The test results indicate that the majority of the hypotheses are statistically validated, demonstrating the robustness of the causal relationship in this research model.

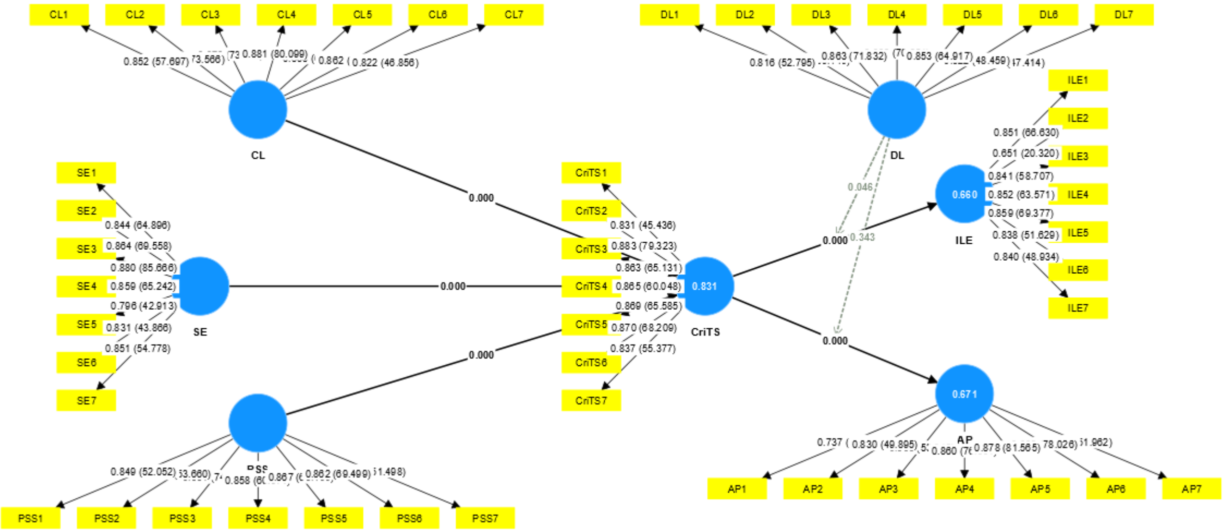

Fig. 2. Hypothesis Result Path.

Fig. 2 illustrates the paths of all hypotheses designed in this study. Table 3 presents the effect sizes of each accepted hypothesis, with calculations based on the guidelines provided by Hair et al. (2017) [68]. Among the proposed hypotheses, one hypothesis related to the moderating variable was rejected.

Table 3. Hypothesis result.

Hypothesis	***β***	***t***	***ρ***	**Results**
H1: CL -> CriTS	0.225	5.244	0.000	Accepted
H2: SE -> CriTS	0.178	4.770	0.000	Accepted
H3: PSS -> CriTS	0.568	12.093	0.000	Accepted
H4: CriTS -> ILE	0.658	17.110	0.000	Accepted
H5: CriTS -> AP	0.252	5.074	0.000	Accepted
H6: DL x CriTS -> ILE	-0.035	1.995	0.046	Accepted
H7: DL x CriTS -> AP	0.023	0.948	0.343	Rejected

Hypothesis 1 posits that cognitive load has a positive and significant influence on critical thinking skills. These results support previous literature [15,16]. This evidence indicates that germane cognitive load, a mental burden that facilitates the construction and automation of knowledge schemas, enhances the acquisition of higher-order thinking skills. Cognitively challenged students who engage with significant content tend to be more proactive in establishing connections between concepts, assessing information, and making fact-based decisions. Students enhance their skills in argumentation, evidence evaluation, and logical reasoning through tasks that incorporate well-structured cognitive components. These are essential competencies for critical thinking. A more succinct expression is that optimally calibrated and meticulously structured cognitive load facilitates repeated practice of critical thinking among students in educational settings. Hypothesis 2 suggests that self-efficacy has a positive and significant influence on critical thinking skills. This result supports previous literature [21,24]. The results indicate that self-efficacy exerts a positive and significant influence on the critical thinking skills of college students. This holds significant strategic ramifications for the formulation of learning policies and practices in universities. Self-efficacy refers to an individual's conviction in their capacity to accomplish a task or attain a specific objective. It is associated with learning motivation and establishes a cognitive and emotional foundation for critical and reflective thinking. Students with high self-efficacy are more inclined to engage in deep cognitive activities, undertake intellectual risks, and make decisions in uncertain situations. All of these constitute essential competencies for critical thinking.

Hypothesis 3 posits that problem-solving skills have a positive and significant influence on critical thinking skills. This result is in line with previous research [27,28]. This finding demonstrates that problem-solving skills significantly affect critical thinking skills in Indonesian higher education, thereby improving the understanding of how essential cognitive skills can promote the development of higher-order thinking. Problem-solving skills involve students' abilities to identify issues, analyze root causes, devise alternative solutions, and critically evaluate results. This process directly involves essential elements of critical thinking, such as logical analysis, argument assessment, and evidence-based decision-making. Problem-solving skills are essential not only for academic and professional contexts but also significantly influence students' development of critical thinking abilities. The educational implications of these findings are highly relevant for curriculum developers and educators in Indonesian engineering programs. Critical thinking cannot be passively acquired through simple exposure to information; it must be actively fostered through engagement in challenging and contextually pertinent problem-solving tasks.

Hypothesis 4 posits that critical thinking skills have a positive and significant influence on immersive learning experiences. This result is in line with previous literature [31, 40]. These results indicate that critical thinking skills positively and significantly influence immersive learning experiences among college students. This reinforces the notion that advanced cognitive skills are crucial for maximizing the benefits of immersive technology-driven education. Critical thinking entails the logical and reflective analysis, evaluation, and synthesis of disparate information. These skills are essential for navigating complex and non-linear learning experiences, such as those encountered in immersive learning environments. Students proficient in critical thinking typically excel at navigating interactive digital content, engaging in independent exploration, and comprehending simulations or augmented reality (AR). This enhances learning by making it more comprehensive, pertinent, and intellectually significant. These findings have significant implications for the development of immersive learning designs in engineering education in Indonesian higher education. Contemporary technologies such as virtual reality, augmented reality, and simulation-based learning serve not merely as visual aids, but also as methodologies that necessitate active perceived cognitive engagement from students. Moreover, Hypothesis 5 posits that critical thinking skills have a positive and significant influence on academic performance. This result is in line with previous studies [48,50]. This finding illustrates the considerable and beneficial effect of critical thinking skills on the perceived academic performance of students in Indonesian engineering education, significantly contributing to the existing pedagogical discourse. A key indicator of cognitive literacy is critical thinking, which involves the ability to logically synthesize, evaluate, and analyze information. Students with advanced critical thinking skills are more adept at comprehending material thoroughly, assessing complex arguments, and executing academic tasks through a reflective and evidence-based methodology. This positions critical thinking as not merely an ancillary skill, but as the foremost determinant of outstanding academic achievement. This relationship has considerable ramifications for the instructional design and assessment methodologies in engineering education in Indonesian higher education. Studies have shown that educational settings that promote critical thinking significantly improve students' perceived academic performance, both in terms of quantity and quality.

Hypothesis 6 posits that the moderating effect of digital literacy on the relationship between critical thinking skills and immersive learning experiences is negative and significant. The results of this study extend previous research [16,60]. Digital literacy was found to significantly and negatively moderate the relationship between critical thinking skills and immersive learning experiences. The study indicates a weak although statistically significant negative moderating effect of digital literacy on the connection between critical thinking skills and immersive learning experiences. A potential reason is that students possessing greater digital literacy may prioritize technical exploration of digital capabilities over introspective cognitive engagement, thereby augmenting superfluous cognitive activity and diminishing the role of critical thinking in perceived immersion. Alternatively, this result may reflect measurement limitations, as digital literacy in this study primarily captures functional technological competence rather than strategic or metacognitive technology use. Consequently, the finding indicates that digital literacy is not harmful; rather, technological proficiency alone may be inadequate to enhance immersive learning without intentional cognitive regulation.

This transforms the utilization of technology in engineering education in Indonesian higher education. In this scenario, enhanced digital literacy may render critical thinking skills less effective in engaging individuals with virtual reality, augmented reality, or interactive simulation-based learning. A theory posits that students proficient in technology prioritize the technical and exploratory aspects of media learning over the profound cognitive processes essential for transformative immersive experiences. In other words, superficial digital skills serve more as a cognitive distraction than as instruments for critical reflection. This discovery has yielded significant insights, particularly regarding the advancement of high-tech education in higher learning institutions. Educators and curriculum developers cannot presume that students proficient in technology will inherently exhibit greater interest in learning. Conversely, employing technology without a defined framework for critical thinking may result in extrinsic cognitive load, thereby impeding students' ability to reflect on their thought processes. Consequently, it is essential to ensure that digital literacy skills encompass not only technical competencies but also the cultivation of epistemological awareness, reflective thinking, and the capacity for critical evaluation of the ethics surrounding digital information utilized in immersive learning programs.

Moreover, Hypothesis 7 posits that the moderating effect of digital literacy on the relationship between critical thinking skills and academic performance is positive but insignificant. This result contrasts with several previous studies [48,54,62]. The study's findings suggest that digital literacy affects the positive but negligible relationship between critical thinking skills and academic achievement. This illustrates the challenges of utilizing technology in higher education, especially in Indonesia. Critical thinking skills enable students to objectively analyze information, construct logical arguments, and make sound academic decisions from a psychological perspective. It is often assumed that acquiring technological skills can enhance proficiency in these areas. This result indicates that the correlation between digital literacy and moderation is positive, yet insufficiently robust to significantly influence the extent to which critical thinking contributes to students' academic success. Acquiring digital skills does not necessarily alter students' perceptions of their learning outcomes. To comprehend the implications of this finding, one must understand the current functioning of higher education. Students may possess proficiency in digital technology and have access to it; however, this does not necessarily imply that they can effectively apply these skills in academic tasks that necessitate critical thinking, such as composing scientific papers, resolving complex problems, or analyzing data. Declarative digital literacy pertains to technical competencies, whereas strategic digital literacy encompasses the capacity to utilize technology for advanced cognitive processes. A more comprehensive pedagogical approach is necessary to strengthen the relationship between critical thinking and academic achievement while emphasizing the importance of digital literacy to promote digital-based higher-order thinking skills.

Table 4. Intervening effect.

Moderate	β	t	ρ
CL -> CriTS -> AP	0.057	3.822	0.000
CL -> CriTS -> ILE	0.148	4.833	0.000
PSS -> CriTS -> AP	0.143	4.859	0.000
PSS -> CriTS -> ILE	0.374	9.123	0.000
SE -> CriTS -> AP	0.045	3.006	0.003
SE -> CriTS -> ILE	0.117	5.020	0.000

The data analysis revealed that the intervening variable, critical thinking skills, significantly mediates the relationships among the hypotheses in this study, as shown in Table 4. First, regarding the relationship between cognitive load and perceived academic performance, it was found that critical thinking skills have a positive and significant mediating influence. Similar results were observed for the mediation of critical thinking skills on the relationship between cognitive load and immersive learning experiences. This study demonstrates that critical thinking skills positively and significantly mediate the relationship between cognitive load and perceived academic performance. This is essential for higher education strategies. This approach offers numerous educational advantages. Students require intellectually stimulating material and collaboration to transform that challenge into a reflective and strategic endeavor. Critical thinking serves as a conduit between cognitive abilities and academic achievement, enabling educational settings to evaluate content knowledge as well as analytical and adaptive skills. A substantial and meaningful correlation exists between cognitive load, immersive learning experiences, and high school students' critical thinking abilities, which carries significant theoretical and practical ramifications for technology-enhanced education. This theory demonstrates that cognitive load is not merely a burden but also a cognitive process that can influence learning, particularly when impeded by insufficient resources. Students require robust organizational skills to comprehend intricate information in immersive learning, which is frequently non-linear and multimodal. Cognitive engagement can facilitate involvement even if critical thinking is initially absent. Nonetheless, cognitive load enhances student interest, concentration, and motivation when engaging in challenging critical thinking tasks. This media study is essential for elucidating how cognitive theory-informed instructional design facilitates comprehensive learning.

Second, regarding the relationship between problem-solving skills and perceived academic performance, it was found that critical thinking skills have a positive and significant mediating influence. Similar results were observed for the mediation of critical thinking skills on the relationship between problem-solving skills and immersive learning experiences. Critical thinking skills significantly and positively mediate the association between problem-solving skills and perceived academic performance in college. Critical thinking serves as a strategic connection between practical skills and academic achievement. This mediating relationship indicates that enhancing problem-solving skills without concurrently advancing critical thinking may diminish academic performance, carrying significant implications for curriculum developers and educators. Students capable of resolving technical issues yet lacking critical thinking skills may complete their tasks, but they will be unable to elucidate, generalize, or apply their acquired knowledge. Students who integrate both skills exhibit superior performance and enhanced critical thinking. Students who engage in critical problem-solving outperform those who respond reactively in academic settings. This study demonstrates that critical thinking skills connect practical skills to profound learning engagement in engineering education in Indonesian higher education. They effectively and substantially mediate the connection between immersive learning and problem-solving abilities. These findings underscore the significance of concurrently instructing students in problem-solving and critical thinking. This will enhance their engagement with virtual reality, augmented reality, and interactive simulation-based education. Students who focus solely on technical problem-solving, without engaging in critical thinking, exhibit only a moderate interest in digital content. Students who integrate problem-solving with critical reflection will achieve deeper learning. This is due to their ability to complete tasks, comprehend context, evaluate impact, and derive personal significance from learning.

Finally, regarding the relationship between self-efficacy and perceived academic performance, it was found that critical thinking skills have a positive and significant mediating influence. Similar results were observed for the mediation of critical thinking skills on the relationship between self-efficacy and immersive learning experiences. The research indicated that critical thinking skills significantly and positively mediate the relationship between self-efficacy and perceived academic performance among college students. This fosters critical thinking as a cognitive route to self-efficacy and academic achievement. Mediation significantly enhances cognitive development in students. Motivated and determined students who possess self-efficacy may acquire only essential knowledge if they lack critical thinking skills. Students develop confidence and the capacity to assess information, make informed academic decisions, and appraise their learning process through critical thinking and the cultivation of self-efficacy. Self-efficacy and critical thinking facilitate student success in higher education, particularly in research and problem-solving disciplines. Critical thinking skills substantially and positively mediate the self-efficacy of college students and their immersive learning experiences. This illustrates the necessity of integrating cognitive and affective learning for profound engagement. The findings indicate that merely enhancing self-efficacy is insufficient for fostering an immersive learning experience, which encompasses emotional engagement, perceiving content as authentic, and establishing connections with the material being studied. Students must develop critical thinking skills to assess digital information, identify issues, and comprehend interactive technology thoroughly. Critical thinking enhances students' self-efficacy and advanced cognitive strategies, enabling them to optimize the immersive learning environment, retain knowledge, and perceive learning as more significant.

4.2. Network Analysis

In network analysis, it is crucial to consider the characteristics of edges, which illustrate the connections between nodes. It is essential to comprehend these edge properties [69], as they reflect the strength of connections between nodes in the network analysis. The value or weight of an edge is crucial as it indicates the strength or intensity of the relationship. Additionally, edges may occasionally indicate the direction of power or information flow between nodes. The nature of the relationship indicated the strength of association between the educational constructs in the network. The analysis characterized the network's structure and dynamics based on edge characteristics. Fig. 3 illustrated the network at the domain level.

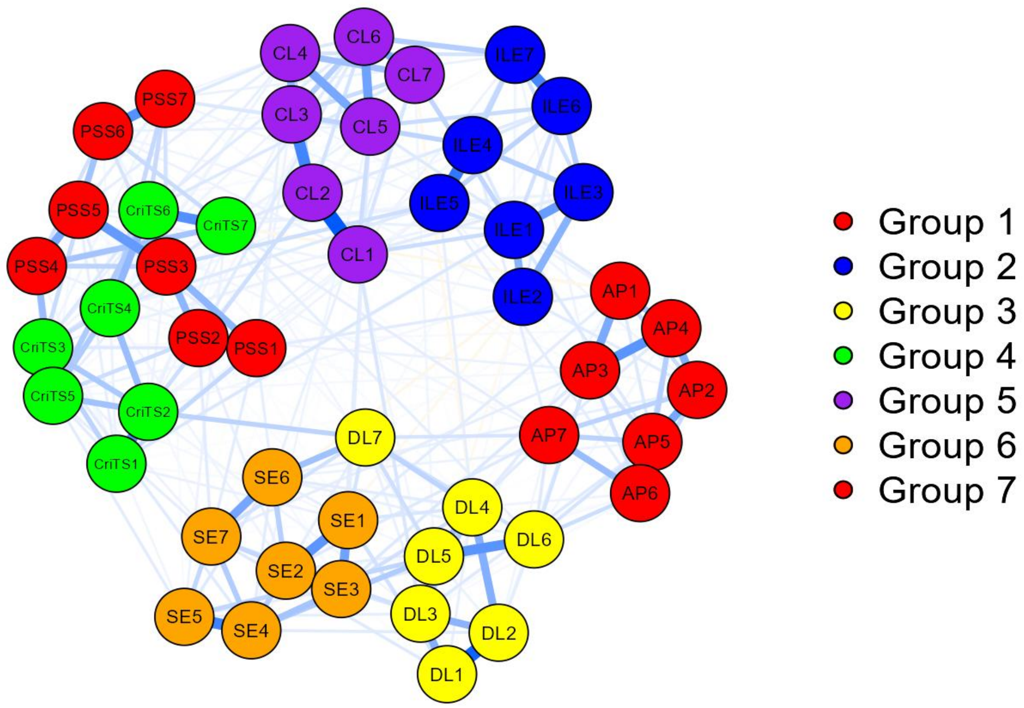

Fig. 3. Network Analysis Relationship.

The examined domain-level network comprised 49 nodes (representing entities or variables) and 363 non-zero edges (representing connections between nodes), as shown in Fig. 3. This structure indicates that the distinct entities were interconnected in various manners. The network primarily concentrated on the complexity of the relationships. This facilitated a more detailed examination of the domain-level network, essential for comprehending the interplay of these factors. It was deduced that the constructs CL, SE, PSS, CritTS, ILE, AP, and DL were represented by multiple nodes (indicators) within their respective categories.

Table 5. Centrality research variables relationship network

	Network			
Variable	**Betweenness**	**Closeness**	**Strength**	**Expected influence**
AP1	-0.341	-1.473	-2.521	-2.729
AP2	-0.791	-1.264	-0.974	-0.701
AP3	-0.397	-1.025	0.512	0.410
AP4	0.391	-1.041	0.456	0.536
AP5	0.110	-0.932	2.129	1.967
AP6	-0.537	-0.801	0.193	0.311
AP7	0.082	-0.496	-1.506	-1.142
ILE1	0.588	0.335	1.325	1.211
ILE2	-0.847	-0.813	-2.739	-3.788
ILE3	-0.341	-0.338	-0.132	-0.140
ILE4	-0.031	0.057	0.137	0.240
ILE5	0.504	0.376	0.426	0.511
ILE6	-0.734	-0.927	-0.675	-0.431
ILE7	-1.072	-1.303	-0.396	-0.193
DL1	-1.100	-1.293	-1.195	-1.001
DL2	-0.481	-0.738	0.942	0.832
DL3	0.166	-0.351	0.594	0.187
DL4	1.179	0.686	0.898	0.342
DL5	0.250	-0.016	0.629	0.684
DL6	-0.200	-0.373	-0.815	-0.551
DL7	3.177	2.163	-1.044	-0.747
CriTS1	0.053	1.916	-1.267	-0.938
CriTS2	4.668	3.296	1.780	1.669
CriTS3	-0.678	-0.008	-0.282	-0.095
CriTS4	0.194	1.161	-0.162	0.008
CriTS5	-0.059	1.059	0.425	0.509

	Network			
Variable	Betweenness	Closeness	Strength	Expected influence
CriTS6	-0.115	0.776	0.372	0.464
CriTS7	0.166	0.388	0.373	-0.183
CL1	0.138	0.991	-8.272×10^{-4}	0.145
CL2	0.954	1.153	1.162	1.140
CL3	0.588	0.982	0.046	-0.008
CL4	-0.172	0.773	0.931	0.943
CL5	1.235	0.965	0.320	0.420
CL6	0.222	0.754	0.422	0.507
CL7	-0.706	0.174	-1.234	-1.602
SE1	-0.960	-0.851	-0.099	0.061
SE2	-0.819	-0.566	0.606	0.624
SE3	0.053	-0.405	0.940	0.950
SE4	-0.059	-0.304	1.208	0.445
SE5	-0.960	-1.165	-1.563	-1.385
SE6	-0.397	0.238	-0.702	-0.455
SE7	-0.341	0.083	0.631	0.079
PSS1	0.082	0.517	0.257	0.366
PSS2	-0.425	0.267	-0.458	-0.245
PSS3	0.194	-0.036	0.770	0.805
PSS4	-0.425	0.125	-0.088	0.071
PSS5	-0.369	-0.405	0.138	0.265
PSS6	-0.622	-1.003	0.346	0.442
PSS7	-1.016	-1.309	-1.115	-0.808

In network analysis, "node characteristics" refer to the various traits or attributes possessed by nodes within a network [70]. Centrality measures (betweenness, closeness, and degree), distances between nodes, and interconnections were key metrics used to elucidate the function of each node in the analysis. Node attributes encompassed details regarding node connectivity, including the functions of each node and the quantity of direct links between them. Examining the attributes of each node was crucial to understanding their functions, interactions, and the overall structure of the network. Researchers leveraged this information to interpret the network structure [71]. Table 5 presents the study variables for betweenness, closeness, degree, and influence within the domain-level network.

The results of the network analysis in this study illustrate the significance of interconnected concepts in the learning processes of college students, particularly in digital and technology-driven environments. The system comprises 49 nodes and 363 active edges. This network has a limited number of nodes, indicating that the indicators are interconnected in a robust and beneficial manner. The Critical Thinking Skill (CritTS) variable, particularly the CritTS2 indicator, is pivotal within the network, as evidenced by the analysis of metric centrality and expected influence. CritTS2 serves as the primary node linking students' internal ability domains (such as cognitive load, problem-solving skills, and self-efficacy) to learning outcomes (such as perceived academic performance and immersive learning experiences). The betweenness, closeness, and expected influence values were 4.668, 3.296, and 1.669, respectively. These findings indicate that critical thinking transcends being merely an isolated cognitive ability. It serves as a metacognitive catalyst that enhances fundamental cognitive abilities, leading to greater learning engagement and perceived academic achievement.

Additionally, certain nodes within the cognitive load domain, such as CL2 and CL5, as well as specific nodes in the immersive learning domain, including ILE1 and ILE5, exhibited elevated values for closeness centrality and strength. This indicates that students' perceptions of cognitive load and their level of engagement in immersive learning environments significantly influence the coherence of the conceptual network. Conversely, elevated digital literacy (particularly DL7) demonstrated increased betweenness and closeness metrics. Nonetheless, the negative expected influence indicated that elevated digital literacy does not invariably enhance cognitive engagement in the absence of sufficient critical thinking abilities. The findings endorse the notion that students ought to acquire digital literacy and critical thinking concurrently to enhance their learning and perceived academic achievement.

The outcomes of this network analysis significantly influence the planning and delivery of engineering education in Indonesia. The primary objective should be to enhance critical thinking, which connects fundamental skills to educational outcomes. Challenge-based learning should be employed to enhance problem-solving abilities and manage cognitive load. This facilitates deeper cognitive engagement among students while minimizing the strain on their working memory. Third, digital literacy should encompass more than merely the ability to utilize technology. It should also encompass instruments for critical thinking and reflection. When colleges and universities integrate these three elements within an immersive digital learning environment, they can create a more effective, flexible learning ecosystem that enhances student quality over time. This study's network analysis functions at the indicator level, with potential multicollinearity and measurement overlap among indicators evaluated and mitigated within the SEM framework via convergent and discriminant validity assessments, including AVE, composite reliability, and HTMT.

Network analysis was subsequently utilized as an exploratory visualization instrument to investigate relative centrality and connectivity patterns among indicators, rather than to reassess measurement validity. The relationships at the indicator level identified in the network should be interpreted descriptively and in conjunction with the SEM results, recognizing that some conceptual overlap among indicators may persist in self-reported Likert-scale measures.

5. Conclusion

This study demonstrates that critical thinking skills significantly link students' internal attributes, such as cognitive load, self-efficacy, and problem-solving abilities, to their academic achievement and immersive learning experiences in engineering education in Indonesian higher education. The incorporation of augmented reality (AR) and game-based learning in engineering courses enhances classroom engagement and intellectual stimulation. In these circumstances, the findings indicate that each cognitive and emotional factor significantly and positively influences the advancement of critical thinking. The results indicate that critical thinking improves the depth of learning and perceived academic performance by facilitating students' ability to analyze, evaluate, and contemplate complex digital content and immersive scenarios. This study contributes to existing literature by employing a multilayered structural model that integrates cognitive psychology and instructional technology.

While the findings provide valuable pedagogical insights, they must be interpreted cautiously due to the correlational design, dependence on self-reported measures, and lack of longitudinal or experimental validation. The findings of this study are consequently restricted to guiding instructional design rather than influencing educational policy or extensive curricular reform. The results indicate that combining immersive learning technologies with organized opportunities for critical thinking and reflective engagement may improve students' perceived learning experiences in engineering education. Nevertheless, comprehensive educational or policy recommendations necessitate additional validation via experimental, longitudinal, or multi-context studies.

Despite the significance of the results, this study has several limitations. The study employed a cross-sectional design with convenience sampling of Indonesian engineering students, which may limit the generalizability of the findings to other academic disciplines or contexts. Furthermore, the finding that digital literacy exerts moderating effects—potentially hindering immersive learning in certain contexts—suggests that digital competence alone may be insufficient without adequate pedagogical support. Furthermore, dependence on self-reported data may introduce response biases, necessitating the use of longitudinal or experimental designs in future research. Future research should employ longitudinal methods to investigate the evolution of critical thinking skills in immersive and game-based environments. Experiments may elucidate the mechanisms underlying phenomena, particularly regarding digital literacy as both a cognitive asset and a potential impediment. Moreover, employing qualitative methodologies such as think-aloud protocols or in-depth interviews in conjunction with AR-based learning systems may enhance researchers' understanding of students' cognitive processes and learning behaviors. Finally, incorporating participants from disciplines beyond engineering would facilitate the testing of the proposed model across a broader spectrum of academic fields.

All the Declarations and Statements

Author Contributions Statement

Hendra Hidayat – Conceptualization, Methodology, and Supervision: Proposed research ideas, Constructed the overall framework, and supervised project execution.
Dewi Artati Padmo Putri – Data Curation and Software Implementation: Handled data acquisition, dataset preprocessing, and implementing the research model.
Wahyu Sakti Gunawan Irianto – Formal Analysis, Visualization, and Statistical Analysis: Performed in-depth analysis of experimental results, prepared performance charts, and ensured the statistical robustness of the evaluation.
Putrinda Inayatul Maula – Writing – Review and Editing, and Project Management: Reviewed and edited the manuscript, ensured clarity and coherence, and helped coordinate project milestones and deadlines.
Diki Diki – Writing – Drafted the initial manuscript, contributed to the literature survey, and documented the technical background of the study.

All authors have read and agreed to the published version of the manuscript.

Conflict of Interest Statement

The authors declare no conflicts of interest.

Funding Declaration

This research was supported by the grant 1503/UN35.15/LT/2025 from Lembaga Penelitian dan Pengabdian Masyarakat Universitas Negeri Padang.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethical Declarations

The authors declare that this study did not involve experiments on animals. Research activities involving human participants were conducted in accordance with institutional and national ethical standards. Informed consent was obtained from parents or legal guardians, and participation was voluntary. All data were anonymized to ensure confidentiality and privacy protection.

Acknowledgments

The authors would like to thank Lembaga Penelitian dan Pengabdian Masyarakat Universitas Negeri Padang for funding this work with a contract number: 1503/UN35.15/LT/2025.

Declaration of Generative AI in Scholarly Writing

None.

Abbreviations

The following abbreviations are used in this manuscript:

AR - Augmented Reality
CL - Cognitive Load
SE - Self-Efficacy
PSS - Problem-Solving Skill
AP - Academic Performance
CriTS - Critical Thinking Skill
DL - Digital Literacy
ILE - Immersive Learning Experience

References

[1] T. Van Truong and T. H. Dung, "The Application of Information Technology in Teaching at University and College Levels in the Context of the Fourth Industrial Revolution," *European Journal of Applied Science, Engineering and Technology*, vol. 2, no. 4, pp. 66–73, Jul. 2024, doi: 10.59324/ejaset.2024.2(4).03.

[2] G. Lampropoulos, E. Keramopoulos, K. Diamantaras, and G. Evangelidis, "Augmented Reality and Gamification in Education: A Systematic Literature Review of Research, Applications, and Empirical Studies," *Applied Sciences*, vol. 12, no. 13, p. 6809, Jul. 2022, doi: 10.3390/app12136809.

[3] M. A. Almulla and W. M. Al-Rahmi, "Integrated Social Cognitive Theory with Learning Input Factors: The Effects of Problem-Solving Skills and Critical Thinking Skills on Learning Performance Sustainability," *Sustainability*, vol. 15, no. 5, p. 3978, Feb. 2023, doi: 10.3390/su15053978.

[4] V. Sukackė *et al.*, "Towards Active Evidence-Based Learning in Engineering Education: A Systematic Literature Review of PBL, PjBL, and CBL," *Sustainability*, vol. 14, no. 21, p. 13955, Oct. 2022, doi: 10.3390/su142113955.

[5] A. Vidak, I. Movre Šapić, V. Mešić, and V. Gomzi, "Augmented reality technology in teaching about physics: a systematic review of opportunities and challenges," *Eur J Phys*, vol. 45, no. 2, p. 023002, Mar. 2024, doi: 10.1088/1361-6404/ad0e84.

[6] H. Ateş and M. Polat, "Leveraging augmented reality and gamification for enhanced self-regulation in science education," *Educ Inf Technol (Dordr)*, Mar. 2025, doi: 10.1007/s10639-025-13481-0.

[7] M. F. Elaby, H. M. Elwishy, S. F. Moatamed, M. A. Abdelwahed, and A. E. Rashiedy, "Does design-build concept improve problem-solving skills? An analysis of first-year engineering students," *Ain Shams Engineering Journal*, vol. 13, no. 6, p. 101780, Nov. 2022, doi: 10.1016/j.asej.2022.101780.

[8] O. Ancan Bastias, J. Diaz, and C. O. Rodriguez, "Evaluation of Critical Thinking in Online Software Engineering Teaching: A Systematic Mapping Study," *IEEE Access*, vol. 9, pp. 167015–167026, 2021, doi: 10.1109/ACCESS.2021.3135245.

[9] G. Baxter and T. Hainey, "Using immersive technologies to enhance the student learning experience," *Interactive Technology and Smart Education*, vol. 21, no. 3, pp. 403–425, Jul. 2024, doi: 10.1108/ITSE-05-2023-0078.

[10] G. Makransky and G. B. Petersen, "The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality," *Educ Psychol Rev*, vol. 33, no. 3, pp. 937–958, Sep. 2021, doi: 10.1007/s10648-020-09586-2.

[11] M. Vásquez-Carbonell, "A Systematic Literature Review of Augmented Reality in Engineering Education: Hardware, Software, Student Motivation & Development Recommendations," Digital Education Review, no. 41, pp. 249–267, 2022, doi: 10.1344/der.2022.41.249-267.

[12] J. Zhang, W. A. J. Wan Yahaya, M. Sanmugam, and Y. Dai, "Assessing Cognitive Load, Performance, and Motivation in Design History Classes Through an Augmented Reality Application," *Sage Open*, vol. 15, no. 2, Apr. 2025, doi: 10.1177/21582440251335387.
[13] V. Czok, M. Krug, S. Müller, J. Huwer, and H. Weitzel, "Learning Effects of Augmented Reality and Game-Based Learning for Science Teaching in Higher Education in the Context of Education for Sustainable Development," *Sustainability*, vol. 15, no. 21, p. 15313, Oct. 2023, doi: 10.3390/su152115313.
[14] J. Sweller, "Cognitive load theory, learning difficulty, and instructional design," *Learn Instr*, vol. 4, no. 4, pp. 295–312, Jan. 1994, doi: 10.1016/0959-4752(94)90003-5.
[15] J. Buchner, K. Buntins, and M. Kerres, "The impact of augmented reality on cognitive load and performance: A systematic review," *J Comput Assist Learn*, vol. 38, no. 1, pp. 285–303, Feb. 2022, doi: 10.1111/jcal.12617.
[16] J. Sweller, "Cognitive load theory and educational technology," *Educational Technology Research and Development*, vol. 68, no. 1, pp. 1–16, Feb. 2020, doi: 10.1007/s11423-019-09701-3.
[17] N. A. M. Mokmin, S. Hanjun, C. Jing, and S. Qi, "Impact of an AR-based learning approach on the learning achievement, motivation, and cognitive load of students in a design course," *Journal of Computers in Education*, vol. 11, no. 2, pp. 557–574, Jun. 2024, doi: 10.1007/s40692-023-00270-2.
[18] M. Arztmann, J. L. Domínguez Alfaro, L. Hornstra, J. Jeuring, and L. Kester, "In-game performance: The role of students' socio-economic status, self-efficacy and situational interest in an augmented reality game," *British Journal of Educational Technology*, vol. 55, no. 2, pp. 484–498, Mar. 2024, doi: 10.1111/bjet.13395.
[19] S. Cai, C. Liu, T. Wang, E. Liu, and J. Liang, "Effects of learning physics using Augmented Reality on students' self-efficacy and conceptions of learning," *British Journal of Educational Technology*, vol. 52, no. 1, pp. 235–251, Jan. 2021, doi: 10.1111/bjet.13020.
[20] V. Czok and H. Weitzel, "Impact of Augmented Reality and Game-Based Learning for Science Teaching: Lessons from Pre-Service Teachers," *Applied Sciences*, vol. 15, no. 5, p. 2844, Mar. 2025, doi: 10.3390/app15052844.
[21] S. Y. Othman, E. Ghallab, S. Eltaybani, and A. M. Mohamed, "Effect of using gamification and augmented reality in mechanical ventilation unit of critical care nursing on nurse students' knowledge, motivation, and self-efficacy: A randomized controlled trial," *Nurse Educ Today*, vol. 142, p. 106329, Nov. 2024, doi: 10.1016/j.nedt.2024.106329.
[22] E. Yıldız-Feyzioğlu and R. Kıran, "Investigating the Relationships between Self-efficacy for Argumentation and Critical Thinking Skills," *J Sci Teacher Educ*, vol. 33, no. 5, pp. 555–577, Jul. 2022, doi: 10.1080/1046560X.2021.1967568.
[23] A. Yusuf, S. Bello, N. Pervin, and A. K. Tukur, "Implementing a proposed framework for enhancing critical thinking skills in synthesizing AI-generated texts," *Think Skills Creat*, vol. 53, p. 101619, Sep. 2024, doi: 10.1016/j.tsc.2024.101619.
[24] F. Keshmiri, "The effect of gamification in entrepreneurship and business education on pharmacy students' self-efficacy and learning outcomes," *BMC Med Educ*, vol. 25, no. 1, p. 491, Apr. 2025, doi: 10.1186/s12909-025-07052-7.
[25] C.-Y. Chung, N. Awad, and I.-H. Hsiao, "Collaborative programming problem-solving in augmented reality: Multimodal analysis of effectiveness and group collaboration," *Australasian Journal of Educational Technology*, vol. 37, no. 5, pp. 17–31, Dec. 2021, doi: 10.14742/ajet.7059.
[26] S. M. Schöbel, A. Janson, and J. M. Leimeister, "Gamifying Online Training in Management Education to Support Emotional Engagement and Problem-solving Skills," *Journal of Management Education*, vol. 47, no. 2, pp. 166–203, Apr. 2023, doi: 10.1177/10525629221123287.
[27] Y. Cheng, M.-H. Lee, C.-S. Yang, and P.-Y. Wu, "Hands-on interaction in the augmented reality (AR) chemistry laboratories enhances the learning effects of low-achieving students: a pilot study," *Interactive Technology and Smart Education*, vol. 21, no. 1, pp. 44–66, Jan. 2024, doi: 10.1108/ITSE-04-2022-0045.
[28] M. Maryana, C. Halim, and H. Rahmi, "The Impact of Gamification on Student Engagement and Learning Outcomes in Mathematics Education," *International Journal of Business, Law, and Education*, vol. 5, no. 2, pp. 1697–1608, Jun. 2024, doi: 10.56442/ijble.v5i2.682.
[29] S. K. Park and H. J. Kim, "Development and Evaluation of Virtual Reality-based Simulation Content for Nursing Students Regarding Emergency Triage," *Journal of Korean Academy of Fundamentals of Nursing*, vol. 30, no. 2, pp. 292–301, May 2023, doi: 10.7739/jkafn.2022.30.2.292.
[30] M. Tasadduq, M. S. Khan, R. M. A. Nawab, M. H. Jamal, and M. T. Chaudhry, "Exploring the effects of gamification on students with rote learning background while learning computer programming," *Computer Applications in Engineering Education*, vol. 29, no. 6, pp. 1871–1891, Nov. 2021, doi: 10.1002/cae.22428.
[31] H. V. Stenseth *et al.*, "Simulation-Based Learning Supported by Technology to Enhance Critical Thinking in Nursing Students: Scoping Review," *J Med Internet Res*, vol. 27, p. e58744, Feb. 2025, doi: 10.2196/58744.
[32] G. Lampropoulos, E. Keramopoulos, K. Diamantaras, and G. Evangelidis, "Integrating Augmented Reality, Gamification, and Serious Games in Computer Science Education," *Educ Sci (Basel)*, vol. 13, no. 6, p. 618, Jun. 2023, doi: 10.3390/educsci13060618.
[33] T. Demircioglu, M. Karakus, and S. Ucar, "Developing Students' Critical Thinking Skills and Argumentation Abilities Through Augmented Reality–Based Argumentation Activities in Science Classes," *Sci Educ (Dordr)*, vol. 32, no. 4, pp. 1165–1195, Aug. 2023, doi: 10.1007/s11191-022-00369-5.
[34] H. Faridi, N. Tuli, A. Mantri, G. Singh, and S. Gargrish, "A framework utilizing augmented reality to improve critical thinking ability and learning gain of the students in Physics," *Computer Applications in Engineering Education*, vol. 29, no. 1, pp. 258–273, Jan. 2021, doi: 10.1002/cae.22342.
[35] P. Wongklang and J. Wipatsopakron, "Development of Problem-Based Mobile Augmented Reality Application to Enhance Creative Problem-Solving Skills for Undergraduate Students," *International Journal of Interactive Mobile Technologies (iJIM)*, vol. 18, no. 07, pp. 53–67, Apr. 2024, doi: 10.3991/ijim.v18i07.42261.
[36] F. Rahmayani, "Development of E-Book Integrated Augmented Reality Based on STEM Approaches to Improve Critical Thinking and Multiple Representation Skills in Learning Physics," *International Journal of Information and Education Technology*, vol. 14, no. 4, pp. 632–641, 2024, doi: 10.18178/ijiet.2024.14.4.2087.

[37] F. Arici and M. Yilmaz, “An examination of the effectiveness of problem-based learning method supported by augmented reality in science education,” *J Comput Assist Learn*, vol. 39, no. 2, pp. 446–476, Apr. 2023, doi: 10.1111/jcal.12752.
[38] M. Weatherton and E. E. Schussler, “Success for All? A Call to Re-examine How Student Success Is Defined in Higher Education,” *CBE—Life Sciences Education*, vol. 20, no. 1, p. es3, Mar. 2021, doi: 10.1187/cbe.20-09-0223.
[39] A. Cabrera-Duffaut, A. M. Pinto-Llorente, and A. Iglesias-Rodríguez, “Immersive learning platforms: analyzing virtual reality contribution to competence development in higher education—a systematic literature review,” *Front Educ (Lausanne)*, vol. 9, Jul. 2024, doi: 10.3389/feduc.2024.1391560.
[40] F. Tursunova, N. Oripova, M. Muhammadiyeva, S. Nurullayeva, S. Hamroyev, and I. Tishabaeva, “Augmented Reality and AI in Higher Education: Creating Immersive Learning Experiences,” in *2024 International Conference on Knowledge Engineering and Communication Systems (ICKECS)*, IEEE, Apr. 2024, pp. 1–5, doi: 10.1109/ICKECS61492.2024.10617355.
[41] K. Alhazzaa and W. Yan, “Immersive technologies in Education: Exploring user experience and engagement in building energy simulations through AR and VR,” *Computers & Education: X Reality*, vol. 6, p. 100097, Jun. 2025, doi: 10.1016/j.cexr.2025.100097.
[42] M. Bigonah, F. Jamshidi, and D. Marghitu, “Immersive Agricultural Education,” in Cases on Collaborative Experiential Ecological Literacy for Education, IGI Global, 2024, pp. 26–76. doi: 10.4018/979-8-3693-1710-5.ch002.
[43] R. Damaševičius and T. Sidekersniene, “Designing Immersive Gamified Experiences in the Metaverse for Enhanced Student Learning,” in *2023 International Conference on Intelligent Metaverse Technologies & Applications (iMETA)*, IEEE, Sep. 2023, pp. 1–6, doi: 10.1109/iMETA59369.2023.10294971.
[44] A. Lu, C. S. K. Wong, R. Y. H. Cheung, and T. S. W. Im, “Supporting Flipped and Gamified Learning With Augmented Reality in Higher Education,” *Front Educ (Lausanne)*, vol. 6, Apr. 2021, doi: 10.3389/feduc.2021.623745.
[45] L. Jaramillo-Mediavilla, A. Basantes-Andrade, M. Cabezas-González, and S. Casillas-Martín, “Impact of Gamification on Motivation and Academic Performance: A Systematic Review,” *Educ Sci (Basel)*, vol. 14, no. 6, p. 639, Jun. 2024, doi: 10.3390/educsci14060639.
[46] G. Lampropoulos and A. Sidiropoulos, “Impact of Gamification on Students’ Learning Outcomes and Academic Performance: A Longitudinal Study Comparing Online, Traditional, and Gamified Learning,” *Educ Sci (Basel)*, vol. 14, no. 4, p. 367, Apr. 2024, doi: 10.3390/educsci14040367.
[47] J. M. Molina-Espinosa, P. Suárez-Brito, B. Gutiérrez-Padilla, E. O. López-Caudana, and M. González-Mendoza, “Academic performance as a driver for the development of reasoning for complexity and digital transformation competencies,” *Front Educ (Lausanne)*, vol. 9, Nov. 2024, doi: 10.3389/feduc.2024.1426183.
[48] R. Malhotra, M. Massoudi, and R. Jindal, “Shifting from traditional engineering education towards competency-based approach: The most recommended approach-review,” *Educ Inf Technol (Dordr)*, vol. 28, no. 7, pp. 9081–9111, Jul. 2023, doi: 10.1007/s10639-022-11568-6.
[49] L. Anthonysamy, P. Sugendran, L. O. Wei, and T. S. Hoon, “An improved metacognitive competency framework to inculcate analytical thinking among university students,” *Educ Inf Technol (Dordr)*, vol. 29, no. 17, pp. 22475–22497, Dec. 2024, doi: 10.1007/s10639-024-12678-z.
[50] Z. Gao, J.-H. Cheah, X.-J. Lim, and X. Luo, “Enhancing academic performance of business students using generative AI: An interactive-constructive-active-passive (ICAP) self-determination perspective,” *The International Journal of Management Education*, vol. 22, no. 2, p. 100958, Jul. 2024, doi: 10.1016/j.ijme.2024.100958.
[51] M. C. Martínez-Bravo, C. Sádaba Chalezquer, and J. Serrano-Puche, “Dimensions of Digital Literacy in the 21st Century Competency Frameworks,” *Sustainability*, vol. 14, no. 3, p. 1867, Feb. 2022, doi: 10.3390/su14031867.
[52] Y. Erdat, R. E. Sezer Ceren, L. Ozdemir, F. Uslu-Sahan, and A. Bilgin, “Influence of technical, cognitive and socio-emotional factors on digital literacy in nursing students assessed using structural equation modeling,” *Nurse Educ Today*, vol. 130, p. 105937, Nov. 2023, doi: 10.1016/j.nedt.2023.105937.
[53] H. Hidayat, Z. Ardi, A. I. Ahlunnazak, D. Harmanto, C. T. Orji, and M. R. M. Isa, “Determining the Influence of Digital Literacy on Learning Personal Competence: The Moderating Role of Fear of Missing Out,” *European Journal of Educational Research*, vol. 13, no. 4, pp. 1775–1790, Oct. 2024, doi: 10.12973/eu-jer.13.4.1775.
[54] N. Nevrelova, L. Korenova, Z. Lavicza, N. Bruzkova, and A. Schmid, “Enhancing digital literacy in primary education through augmented reality,” *Front Educ (Lausanne)*, vol. 9, Nov. 2024, doi: 10.3389/feduc.2024.1390491.
[55] F. Tang, “Understanding the role of digital immersive technology in educating the students of English language: does it promote critical thinking and self-directed learning for achieving sustainability in education with the help of teamwork?,” *BMC Psychol*, vol. 12, no. 1, p. 144, Mar. 2024, doi: 10.1186/s40359-024-01636-6.
[56] L. Rakhimzhanova, D. Issabayeva, J. Kultan, N. Baimuldina, Z. Issabayeva, and Z. Aituganova, “Using Augmented Reality to Teach Digital Literacy Course to Primary School Children with Special Educational Needs,” *European Journal of Educational Research*, vol. 14, no. 1, pp. 55–71, Jan. 2025, doi: 10.12973/eu-jer.14.1.55.
[57] B. Y. Yenioglu, F. Ergulec, and S. Yenioglu, “Augmented reality for learning in special education: a systematic literature review,” *Interactive Learning Environments*, vol. 31, no. 7, pp. 4572–4588, Oct. 2023, doi: 10.1080/10494820.2021.1976802.
[58] N. Yuniarti *et al.*, “Augmented reality-based higher order thinking skills learning media: Enhancing learning performance through self-regulated learning, digital literacy, and critical thinking skills in vocational teacher education,” *Eur J Educ*, vol. 59, no. 4, Dec. 2024, doi: 10.1111/ejed.12725.
[59] K. I. Tuxtayevich, P. S. Ahmatovna, M. N. Turgunbayevna, R. M. Rasulovna, T. F. R. Qizi, and Y. N. A. Qizi, “Different Approaches to Enhance Critical Thinking in Digital Education,” *SPAST Reports*, vol. 1, no. 7, Aug. 2024, doi: 10.69848/sreports.v1i7.5086.
[60] L. Cheng, G. Fang, X. Zhang, Y. Lv, and L. Liu, “Impact of social media use on critical thinking ability of university students,” *Library Hi Tech*, vol. 42, no. 2, pp. 642–669, May 2024, doi: 10.1108/LHT-11-2021-0393.
[61] Risnawati, M. Ramadan, K. Baba, S. Hammad, and M. A. Rustaminezhad, “The Impact of Augmented Reality-Based Learning Media on Students’ Digital Literacy Skills: A Study on Junior High School Students,” *Journal of Educational Technology and Learning Creativity*, vol. 2, no. 1, pp. 63–70, Jun. 2024, doi: 10.37251/jetlc.v2i1.1415.

[62] M. Hassan, A. S. Malik, G. Sang, M. Rizwan, I. Mushtaque, and S. Naveed, “Examine the parenting style effect on the academic achievement orientation of secondary school students: The moderating role of digital literacy,” *Front Psychol*, vol. 13, Dec. 2022, doi: 10.3389/fpsyg.2022.1063682.
[63] S. Ding, Y. Zhang, H. Huang, D. Chen, and Z. Gao, “The relationship between digital literacy and K-12 students’ academic performance: mediation effects of problem-solving ability,” in *2024 International Symposium on Educational Technology (ISET)*, IEEE, Jul. 2024, pp. 132–136, doi: 10.1109/ISET61814.2024.00034.
[64]F. Li, L. Cheng, X. Wang, L. Shen, Y. Ma, and A. Y. M. A. Islam, “The causal relationship between digital literacy and students’ academic achievement: a meta-analysis,” *Humanit Soc Sci Commun*, vol. 12, no. 1, p. 108, Jan. 2025, doi: 10.1057/s41599-025-04399-6.
[65] A. Panda and S. Mohapatra, “Research Design,” in The Online Healthcare Community, Emerald Publishing, 2024, pp. 53–62. doi: 10.1108/978-1-83549-140-920241004.
[66] M. Ghasemy, V. Teeroovengadum, J.-M. Becker, and C. M. Ringle, “This fast car can move faster: a review of PLS-SEM application in higher education research,” Higher Education, vol. 80, no. 6, pp. 1121–1152, Dec. 2020, doi: 10.1007/s10734-020-00534-1.
[67] D. Borsboom *et al.*, “Network analysis of multivariate data in psychological science,” *Nature Reviews Methods Primers*, vol. 1, no. 1, p. 58, Aug. 2021, doi: 10.1038/s43586-021-00055-w.
[68] J. Hair, C. L. Hollingsworth, A. B. Randolph, and A. Y. L. Chong, “An updated and expanded assessment of PLS-SEM in information systems research,” *Industrial Management & Data Systems*, vol. 117, no. 3, pp. 442–458, Apr. 2017, doi: 10.1108/IMDS-04-2016-0130.
[69] D. Hevey, “Network analysis: a brief overview and tutorial,” *Health Psychol Behav Med*, vol. 6, no. 1, pp. 301–328, Jan. 2018, doi: 10.1080/21642850.2018.1521283.
[70] B. Wellman, “Network Analysis: Some Basic Principles,” *Sociol Theory*, vol. 1, p. 155, 1983, doi: 10.2307/202050.
[71] S. Tabassum, F. S. F. Pereira, S. Fernandes, and J. Gama, “Social network analysis: An overview,” *WIREs Data Mining and Knowledge Discovery*, vol. 8, no. 5, Sep. 2018, doi: 10.1002/widm.1256.

Authors’ Profiles

Hendra Hidayat is a doctor in technology and vocational education. He is a lecturer in the Department of Electronics Engineering Education, Engineering Faculty of Universitas Negeri Padang, Padang, Indonesia. His current expertise is in the fields of electronics learning technology, electronics engineering, and technopreneurship. His research interests include augmented reality in electronics engineering education, combining gamification and integrated mobile application learning, designing prototype electronics engineering learning, and digital entrepreneurship with AI and mobile apps.

Dewi Artati Padmo Putri is a Professor in educational technology, having received her PhD in educational technology from Florida State University. She is a lecturer in the Department of Educational Technology, Open University, South Tangerang, Indonesia. Her field of expertise focuses on educational technology, learning design, and the use of information technology to improve the quality of the teaching and learning process in the context of open and distance education. Her research interests include integrating pedagogical approaches with digital technology, including the use of learning support systems, interactive learning media, and data-based learning evaluation.

Wahyu Sakti Gunawan Irianto is a senior lecturer in the Informatics Education Study Program at Malang State University, Malang, Indonesia, and holds a doctorate in vocational education from Malang State University. His area of expertise focuses on informatics education, particularly in the context of vocational education and teacher readiness in facing the challenges of Industry 4.0 and the field of informatics. His research also emphasizes technical and vocational education and training (TVET), educational data mining, learning analytics, and the application of machine learning and deep learning in educational contexts. His publications also cover the application of technology in educational settings, including collaborative or differentiated learning, immersive and game-based learning, as well as the integration of information technology in the learning process. In addition, he actively conducts applied research and community engagement related to digital transformation, smart systems, and technology-based empowerment in vocational schools and local communities. Overall, his research interests lie at the intersection of technology, education, and adaptive competency development, with a data-driven and AI-supported pedagogical approach that involves information technology, learning analytics, and innovative pedagogy.

Putrinda Inayatul Maula is a lecturer in Informatics Engineering Education at Malang State University, Malang, Indonesia, and is currently completing her Doctorate in Vocational Education from Malang State University. Her field of expertise focuses on Informatics Engineering Education. Her publications also cover a wide range of topics, including educational data mining, machine learning applications in adaptive learning systems, immersive and cross-platform learning, deep learning–based cyber pedagogy, and the enhancement of 21st-century skills (4C skills) in vocational high school students. She has also conducted applied research related to learning media development, digital literacy integration, and technology-based instructional innovation in vocational education Overall, her research interests lie at the intersection of informatics education, educational technology, and vocational learning innovation, with an emphasis on improving learning effectiveness, student competencies, and instructional quality through data-driven and intelligent learning approaches.

Diki Diki is a lecturer at the Department of Biology, Faculty of Science and Technology, Universitas Terbuka. His main research interests include human genetics and cancer. In addition, he is a staff member at the Research and Innovation Center of Universitas Terbuka. He focuses on the development and application of augmented reality, gamification, and artificial intelligence within this unit.

How to cite this paper

Hendra Hidayat, Dewi Artati Padmo Putri, Wahyu Sakti Gunawan Irianto, Putrinda Inayatul Maula, Diki Diki, "Augmented Reality (AR) and Gamification on Immersive Learning Experiences and Perceived Academic Performance: Using SEM and Network Analysis", International Journal of Modern Education and Computer Science(IJMECS), Vol.18, No.4, pp. 40-58, 2026. DOI:10.5815/ijmecs.2026.04.03