Leveraging Augmented Reality to Cultivate Higher-Order Thinking Skills and Enhance Students' Academic Performance

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***Abstract*—This paper aims to investigate the potential of Augmented Reality (AR) technology as a valuable tool in enhancing students' academic performance through higher-order thinking skills. The participants of this study were students with undergraduate degrees in education at three state level universities, in Indonesia. This research employed a quantitative survey consisting of 26 questionnaire items administered through Google Forms. The results showed the enhancement of higher-order skills through AR integration in education, leading to better academic outcomes. Additionally, the study explored how gender and the selected program impact students' academic performance, showing intricate connections between these variables. The results have significant implications in equipping students with the strong higher-order thinking skills necessary to meet the demands of the modern world.**

***Keywords*—higher-order thinking skills, augmented reality, students' academic performance, problem solving skills, critical thinking skills, creative thinking skills, electronics engineering education**

I. Introduction

As we navigate the changes of the 21st century, technical education has garnered significant attention as a vital pillar in shaping individuals who are both competent and adaptable. The evolution of technology, industrial transformation, and the demands of globalization shape the education landscape vastly different from the past [1–3]. In this context, academic success in technical education should be evaluated based on 21st-century skills that promote creativity, adaptability, high-level skills, and critical thinking among students to face the complex and diverse challenges of the future.

Achieving exceptional academic performance in the 21st century is not solely influenced by education factors. Problem-solving skills, including attitudes and methods, evolve as critical connection between students' academic performance in engineering education and the demands of the 21st century [4, 5]. The ability to think critically and creatively when faced with challenges, the capacity to produce high-quality and positively influential outputs, and an open perspective toward challenges are essential components of measuring academic accomplishment [6]. This correlates with the study conducted by Anwar *et al.* [7] stating that students need a positive outlook and skills to innovate amid changes by critically envisioning a clear and highly desired future self.

Critical and creative thinking skills are essential in developing effective problem-solving skills. Critical thinking entails the ability to delve deeply into analysis, critically evaluate information, and formulate solutions based on thorough understanding [8, 9]. Conversely, creative thinking encourages students to method problem from diverse angles, generate innovative ideas, and craft unique solutions.

Immersive technology-based learning through Augmented Reality (AR), stands out as a teaching method that actively nurtures higher-order thinking skills and fosters innovative ideas. AR stands out as an exceptionally effective technology for enhancing students' academic performance and cultivating higher-order thinking skills due to its unparalleled ability to create immersive learning experiences [10–14]. By overlaying digital content onto the real-world environment, AR engages students in a dynamic and contextualized manner, making abstract concepts more tangible and understandable. The interactive nature of AR not only captures students' attention but also motivates them to delve deeper into subjects, fostering intrinsic curiosity [15]. Nikolic *et al.* [16] revealed that AR facilitates personalized learning by adapting content to individual needs, ensuring that students' progress at their own pace. Therefore, this research also encourages collaboration, which allows students to interact with shared content and develop teamwork and communication skills. Importantly, AR prepares students for the future by introducing them to cutting-edge technologies and offering a multisensory learning experience [17, 18]. With its potential to simulate real-world scenarios, provide data-driven insights, and challenge students with problem-solving tasks, AR emerges as a transformative tool that goes beyond traditional educational approaches, effectively shaping a new paradigm for enhancing academic achievement and critical thinking skills.

AR-based learning effectively builds and enhances learning readiness, introducing game-like elements that stimulate students' interest and engagement, thereby fostering an open mindset towards education. AR facilitates a more interactive and immersive learning experience, where technical knowledge is applied in AR-generated real-world scenarios, effectively connecting theory with practice [19–24]. By integrating AR technology, this study pioneers a novel approach to fostering higher-order thinking skills and enhancing students' academic performance. Previous research by Zhao and Yang [25], which focused solely on learning outcomes with AR, while the novelty of this research lies in investigating how AR not only stimulates student engagement but also nurtures critical thinking, creativity, and problem-solving abilities essential for success

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in the 21st century. Through its comprehensive analysis of the impact of AR on academic performance and higher-order thinking skills, this research contributes to a deeper understanding of the potential of immersive technologies in education.

Learning is fueled by genuine curiosity as well as exploration, experimentation, and problem-solving activities rather than just academic pressure. AR becomes a potent tool in crafting learning experiences that are relevant, challenging, and correlated with 21st-century demands. Through gaming elements and interactive experiences, students develop confidence in tackling initially complex technology [26]. In this regard, AR establishes a user-friendly learning environment and diminishes barriers to technology adoption in learning [27–30]. With a focus on higher-order thinking skills, this study attempts to examine how the use of AR affects the academic performance of engineering education students, demanding critical thinking, creativity, and problem-solving in immersive technology. Encouraging students to engage with simulations and real-life scenarios bridges technology applications with higher-order thinking skills development. Through analyzing how these skills interact and influence students' academic performance, this study aims to deepen understanding of AR's potential in enhancing higher-order thinking skills and students' academic performance in engineering education.

II. Methods

To address the study questions and hypotheses, the methods of Structural Equation Modeling (SEM) analysis were applied, using predefined variables such as Problem-Solving Skills, Critical Thinking Skills, Creative Thinking Skills, and Students' Academic Performance. The research questions for this study are as follows:

1) How do Problem-Solving Skills, Critical Thinking Skills, and Creative Thinking Skills individually influence Students' Academic Performance?
2) What is the collective impact of Problem-Solving Skills, Critical Thinking Skills, and Creative Thinking Skills on Students' Academic Performance?
3) Do Critical Thinking Skills mediate the relationship between Problem-Solving Skills and Students' Academic Performance?
4) Do Critical Thinking Skills mediate the relationship between Creative Thinking Skills and Students' Academic Performance?
5) Are there indirect effects of Problem-Solving Skills and Creative Thinking Skills on Students' Academic Performance through Critical Thinking Skills?

A. *SEM Analysis*

In the initial stage, SEM analysis was applied to test hypotheses and validate the relationships identified in the study. SEM PLS was used as a statistical method to analyze connections between variables in the study model [31, 32]. This method focused on understanding cause-and-effect relationships by constructing a structural equation model and measuring the direct and indirect influences between variables [33]. SEM excels in modeling complex relationships among observed variables, a pivotal factor when the study endeavors to unravel the simultaneous interactions and mutual influences among a myriad of contributing factors [34]. Its prowess in multivariate analysis empowers researchers to comprehensively address the multifaceted nature of reality by accommodating multiple dependent and independent variables seamlessly. Moreover, SEM's ability to confirm underlying theories and rigorously test models against empirical data is paramount for establishing the validity of the study's theoretical constructs. The method's adeptness at handling measurement errors, integrating latent variables, and dissecting mediation and moderation effects enhances the precision and depth of the analysis. By leveraging various types of data, SEM provides a holistic framework that allows for a nuanced exploration of the phenomenon under investigation.

B. *Participants*

The participants in this study were students (N = 250) enrolled in the Information, Electrical, Electronics, and Informatics Engineering programs at three state university in Indonesia. Of the students, 169 respondents (67.6%) were male, while 81 students (32.4%) were female. Furthermore, considering the enrollment year shown by Students Identification Numbers (NIM), the breakdown was as follows, two students' respondent (0.8%) enrolled in 2017, nine (3.6%) registered in 2018, three (1.2%) enlisted in 2019, 49 respondents (19.6%) subscribed in 2020, 67 participants (26.8%) enlisted in 2021, and 120 students (48%) enrolled in 2022. The largest group of respondents belonged to the Electrical Engineering Education program, comprising 91 participants (36.4%). Following this, Information Engineering Education had 59 respondents (23.6%), while other programs accounted for 53 students (21.2%). The Electronics Engineering Education program had 47 student respondents (18.8%).

C. *Instrument*

After creating and utilizing the participant portfolio, they will proceed to conduct an online quantitative survey collected through Google Forms in 2023. The primary data obtained was adapted from a well-established questionnaire previously developed by leading scholars in the field. The instrument included adapted problem-solving skills [35], critical thinking skills [36], creative thinking skills [37], and academic of students' performance [38]. This questionnaire comprised 26 items using a Likert scale measurement, covering response options ranging from (1) strongly disagree/never, (2) disagree/rarely, (3) uncertain/sometimes, (4) agree/often to (5) strongly agree/always. Furthermore, the responses from the questionnaire were tabulated and analyzed using SmartPLS version 3 to test their validity and reliability. There was no missing data in this study. The internal validity and reliability values will be calculated using Cronbach's Alpha, and the results will be attached in the result section of the Measurement Model Evaluation.

D. *Procedures*

Before the experiment commenced, participants were informed about the objectives and procedures of the study and their consent was obtained for participation. Students who were willing were requested to access the "AR Basic Electronics" application, which depicted fundamental material about electronics components, particularly diodes and capacitors. The application's home page is shown in Fig. 1.

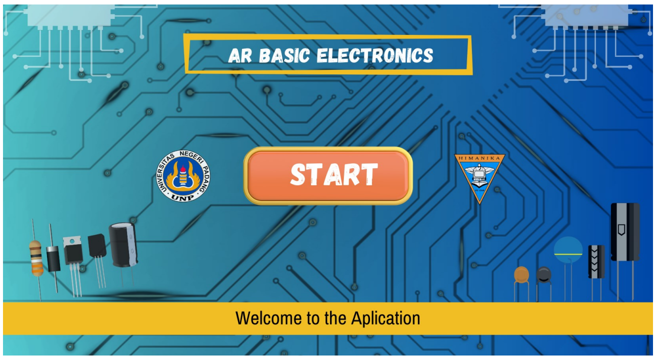

Fig. 1. Application start page.

Fig. 1 shows the initial screen of the application, where the "Start" button leads to the menu page, as depicted in Fig. 2.

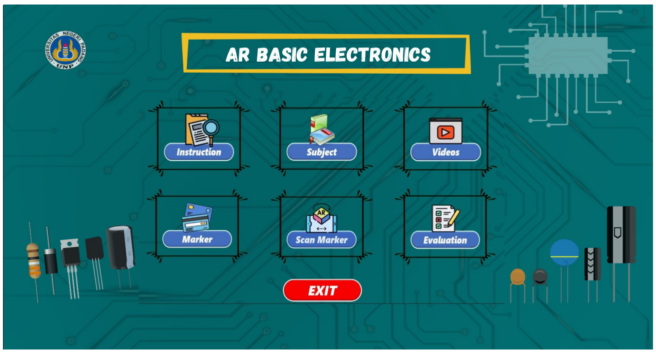

Fig. 2. The application's menu page.

The menu page, as shown in Fig. 2, contained options. The subject material can be accessed by selecting the "Subject" button, and its image is depicted in Fig. 3.

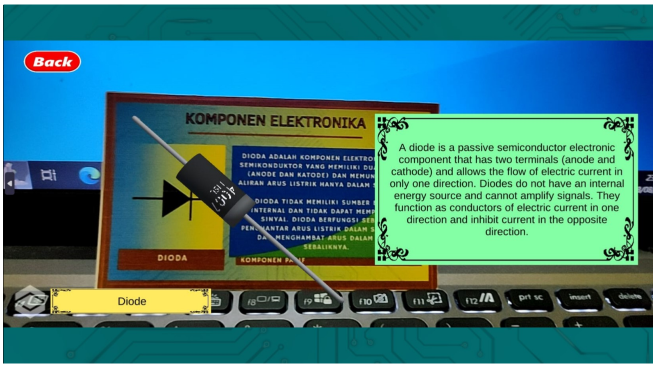

Fig. 3. Diode component material page.

Fig. 4. Capacitor component material page.

Fig. 3 shows a single electronic component, specifically the Diode. The same presentation format is applied to the Capacitor, as shown in Fig. 4.

Fig. 4 presents electronics component, the Capacitor, as observed in the image of the smartphone of students. Meanwhile, Fig. 5 depicts an image showing the implementation of AR.

Fig. 5. Implementation of the AR application.

Fig. 5 offers an overview of the implementation of the AR application. Furthermore, the application featured practice exercises aimed at improving students' understanding of the material, as shown in Fig. 6.

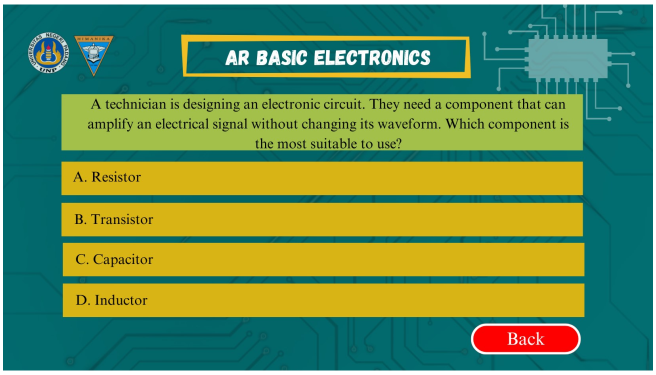

Fig. 6. Quiz page.

Fig. 6 shows the quiz interface intended for completion by students. The scores obtained from this quiz were used to evaluate the effectiveness and success of implementing the AR Basic Electronics application.

III. Result And Discussion

In the field of electronics education, specialized skills were necessary for evaluating students' academic performance. A precise and well-structured evaluation process formed a crucial foundation for measuring students' understanding of the learning materials and their ability to apply technical concepts. Subsequently, the results of the academic performance of students correlate with the stages delineated in the methodology section. In this phase, the analytical methods included SEM PLS grouping, network analysis, and ANOVA were used to enhance the explanation.

A. SEM Analysis

In the initial phase, SEM analysis was used with two stages, where the first step included factor construction (outer model) using measurement variables to form factors representing the constructs within the study [39]. Within this stage, computations of factor loadings were executed, and an evaluation of the reliability of measurement was conducted to ensure their validity. Both convergent and discriminant validity were assessed to guarantee that measurement variables could adequately evaluate distinct constructs with appropriate relationships [40–42]. The second phase entailed the structural equation (inner model), wherein the constructed factors were interconnected to examine the relationships between variables [43, 44]. The PLS-SEM structural equation model derived coefficients through path analysis, showing the strength and direction of relationships between variables [45–48].

1) Measurement model evaluation

The purpose of Measurement Model Assessment (MMA) was to evaluate validity and reliability within the context of statistical and structural analyses such as SEM [49–52]. MMA focused on ensuring that the variables used in the model possessed adequate measurement quality and reliability [53, 54]. The assessment of the measurement model entailed several crucial aspects. Firstly, the level of reliability consistency was assessed using both Cronbach's Alpha (α) and Composite Reliability (CR), both of which had to reach satisfactory values (> 0.7) [55]. The convergent validity was established by scrutinizing outer loadings that achieved significant levels (> 0.7) and ensuring that the Average Variance Extracted (AVE) showed values exceeding 0.5 [56]. Lastly, discriminant validity was confirmed by guaranteeing that the Heterotrait-Monotrait (HTMT) ratio remained below 0.9 [55]. The results showed that each construct within the generated model met the criteria for internal consistency, convergent validity (Table 1), and discriminant validity (Table 2).

Table 1. Measurement model evaluation results (SmartPLS 3)

Variable	Item	Outer Loading	Cronbach Alpha	Composite Reality	AVE > 0.5
Creative Thinking Skills (Cre)	Cre1	0.780	0.924	0.937	0.623
	Cre2	0.738			
	Cre3	0.825			
	Cre4	0.799			
	Cre5	0.751			
	Cre6	0.808			
	Cre7	0.816			
	Cre8	0.795			
	Cre9	0.785			
Critical Thinking Skills (Cri)	Cri1	0.721	0.912	0.928	0.619
	Cri3	0.759			
	Cri4	0.772			
	Cri5	0.774			
	Cri6	0.843			
	Cri7	0.781			
	Cri8	0.813			
	Cri9	0.824			
Problem-Solving Skills (PSQ)	PSQ1	0.849	0.883	0.914	0.681
	PSQ2	0.850			
	PSQ3	0.825			
	PSQ4	0.830			
	PSQ5	0.772			
Academic Performance (Pe)	Pe1	0.885	0.797	0.882	0.714
	Pe2	0.878			
	Pe3	0.767			

Based on Table 1, it is evident that all statement items associated with the variables—Students' Academic Performance, Creative Thinking Skills, Problem-Solving Skills, and Critical Thinking Skills—can be considered valid due to their outer loading values exceeding 0.7.

This is also evident in the Creative Thinking Skills (Cre), all items (Cre1 to Cre9) demonstrate good validity, with outer loading values ranging from 0.738 to 0.825. Critical Thinking Skills (Cri) also exhibit satisfactory validity, with outer loading values ranging from 0.721 to 0.843 for all items (Cri1 to Cri9).

Meanwhile, Problem-Solving Skills (PSQ) display high validity, with outer loading values ranging from 0.772 to 0.850 for all items (PSQ1 to PSQ5). Academic Performance (Pe) also demonstrates good validity, with outer loading values ranging from 0.767 to 0.885 for all items (Pe1 to Pe3). In terms of internal reliability, all variables show high levels of reliability, as evidenced by Cronbach's Alpha values surpassing the threshold of 0.7.

SEM analysis further reveals significant relationships among these variables. The Composite Reality values for each variable indicate a high level of confidence in the proposed model.

Consequently, the results showed that all statements had effectively measured the intended concepts with satisfactory validity within the framework. This observation was underpinned by the primary function of convergent validity, aimed to assess the extent to which measurement variables within the model authentically represented the constructs [57].

Table 2. HTMT ration results (SmartPLS 3)

Variable	Creative Thinking Skills	Critical Thinking Skills	Problem-Solving Quality	Academic of students Performance
Creative Thinking Skills	–	–	–	–
Critical Thinking Skills	0.818	–	–	–
Problem-Solving Quality	0.817	0.896	–	–
Academic of students Performance	0.678	0.796	0.699	–

The data in Table 2 depicted the level of relationships among the variables under study, showing a strong interconnection between creative and critical thinking skills, problem-solving quality, and students' academic performance in engineering education. The significant and high HTMT values (< 0.9) observed between these variables suggested a positive influence of creative and critical thinking skills, along with problem-solving abilities on students' academic performance. In this context, the use of AR in engineering aimed to improve engagement and deeper comprehension, which may have enhanced students' ability to think critically and solve problems, eventually leading to better academic outcomes.

According to Table 3, it is evident that the Standardized Root Mean Square Residual (SRMR) was below 0.1, signifying a good model fit [58, 59]. The Chi-Square value exceeded 0.9, and the Normed Fit Index (NFI), ranging from 0 to 1, method 1, shows a highly fitting model [60]. In the saturated model, where all conceivable relationships were examined, a relatively good fit with the empirical data was established, as evidenced by lower SRMR and Chi-Square values. The model was considered suitable and acceptable entirely.

Table 3. The goodness of fit model

Variable	Saturated Model	Estimated Model
SRMR	0.054	0.071
Chi-Square	652.268	671.283
NFI	0.853	0.849

2) Structural Model Assessment (SMA)

SMA entailed evaluating and analyzing the latent variable used in SEM analysis or path analysis [60]. SMA aimed to gauge how well the constructed model correlated with the available data and to scrutinize its adequacy and validity [61, 62], ensuring that the results were firmly rooted in strong empirical foundations. Evaluating the study questions became crucial, considering the values of T statistics and *p*-values to assess the statistical significance of the data analysis outcomes. Study questions were considered valid when the T statistic value exceeded 1.96 and the *p*-value was less than 0.05, showing a significant influence between the exogenous and endogenous variables [63–65]. Fig. 7 was designated to present the T statistic values.

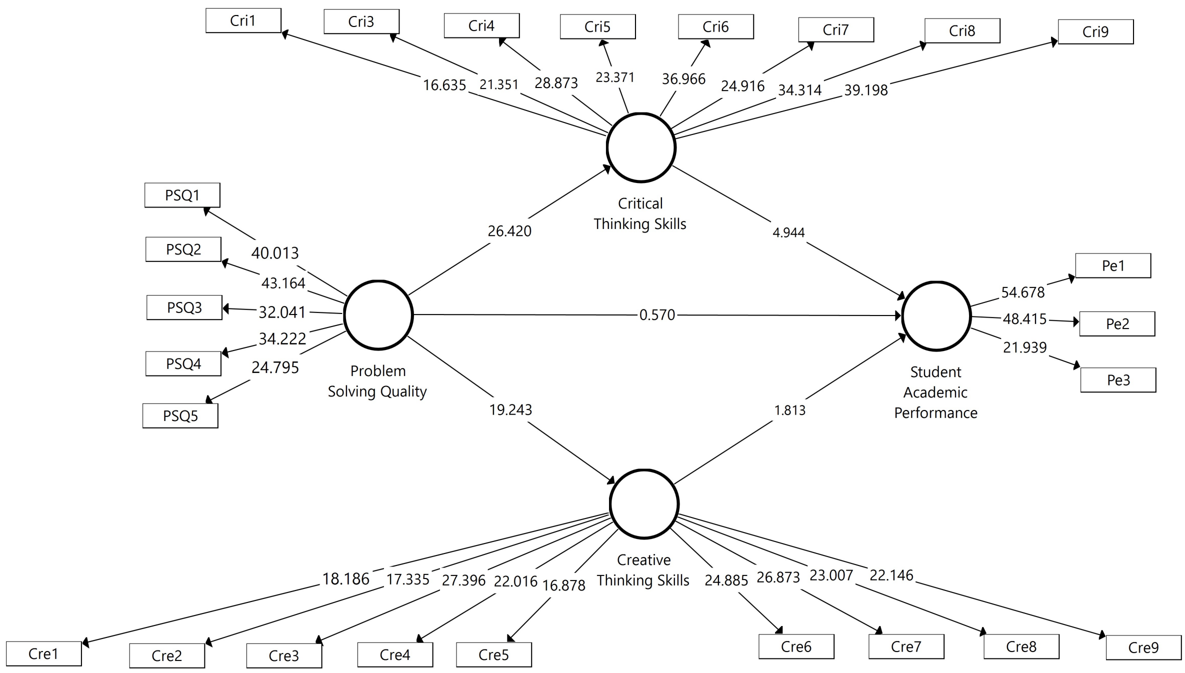

Fig. 7. Model calculation results with T values (SmartPLS 3).

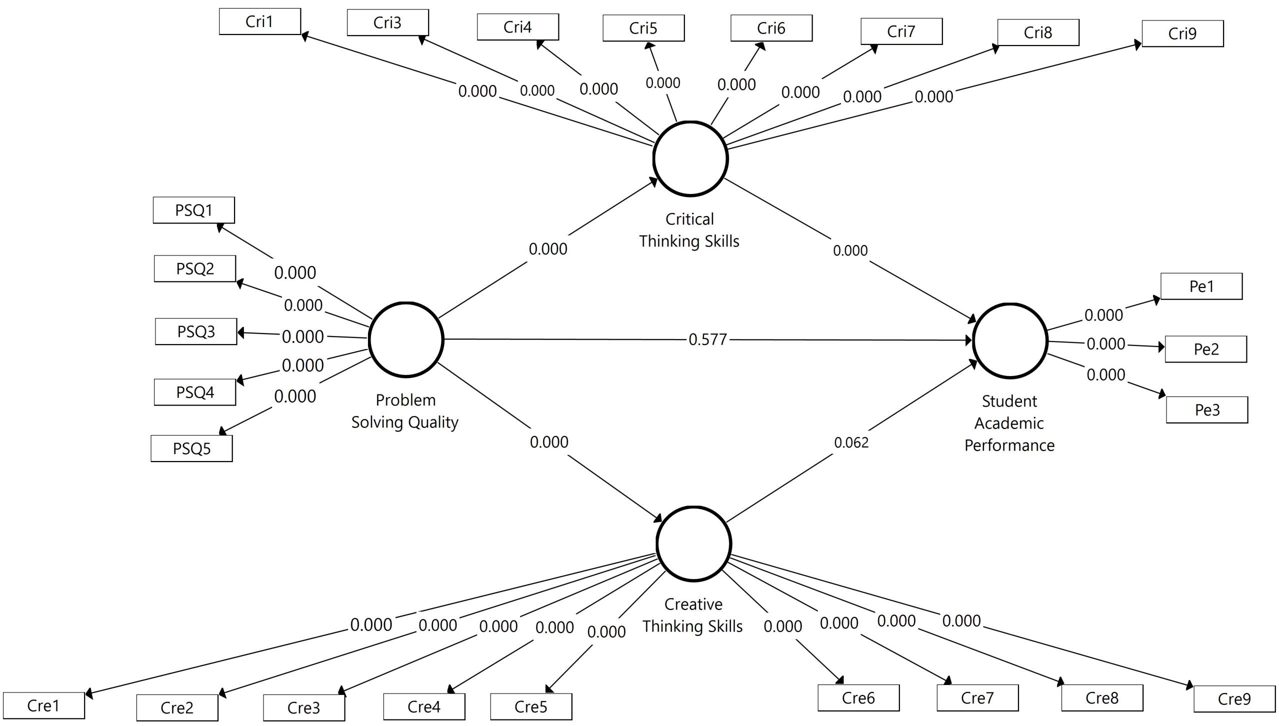

Fig. 8. Model calculation results with p-value (SmartPLS 3).

The data in Fig. 7 showed that all the obtained T statistic values exceeded 1.96. These T statistic values signified strong statistical significance in the relationships between the variables showing a substantial influence. However, the association between Problem-Solving Skills variable and the Students' Academic Performance variable significantly exhibited a T statistic value lower than 1.96. This discrepancy might imply a potential lack of strong statistical significance in the relationship between these variables or could be a chance occurrence. Concurrently, the *p*-values are presented in Fig. 8.

Upon examining Fig. 8, it becomes apparent that the listed *p*-values stand below 0.05 for all variable relationships, except for the correlation between Problem-Solving Skills and Students' Academic Performance elements. *p*-values below 0.05 signified substantial statistical significance in the test outcomes, showing a positive influence among the tested variables. However, concerning the relationship between Problem Solving Skills and Students' Academic Performance, the *p*-value appeared not to meet the significance threshold. This observation might suggest a lack of significant impact within this relationship or a chance of occurrence in the results. Table 4 presents the results of testing study questions in path analysis.

Table 4. Results of the measurement model

Variable	Original Sample (O)	T statistics	*p*-values	Hypotheses
Creative Thinking Skills → Students' Academic Performance	0.157	1.755	0.080	Hypotheses 1 Rejected
Critical Thinking Skills → Students' Academic Performance	0.518	4.875	0.000	Hypotheses 2 Accepted
Problem Solving Quality → Creative Thinking Skills	0.742	19.392	0.000	Hypotheses 3 Accepted
Problem-Solving Quality → Critical Thinking Skills	0.809	27.563	0.000	Hypotheses 4 Accepted
Problem-Solving Quality → Students' Academic Performance	0.055	0.551	0.582	Hypotheses 5 Rejected
Problem-Solving Quality → Critical Thinking Skills → Students' Academic Performance	0.536	6.731	0.000	Hypotheses 6 Accepted
Problem-Solving Quality → Creative Thinking Skills → Students' Academic Performance	0.536	6.731	0.000	Hypotheses 7 Accepted

Table 4 presents the results of the path analysis, establishing connections between the variables in the study and assessing the proposed hypotheses. The evaluation of the original data sample showed crucial results. Firstly, Hypotheses 1, which pertains to the relationship between "Creative Thinking Skills" and "Students' Academic Performance", was rejected due to the *p*-value exceeding the established significance level. The relationship between "Critical Thinking Skills" and "Students' Academic Performance" showed a substantial connection, leading to the acceptance of Hypotheses 2 based on a very low *p*-value. Additionally, the acceptance of both Hypotheses 3 and Hypothesis 4 confirmed the high correlations between the variables, which were bolstered by extremely low *p*-values.

When considering the relationship between "Problem-Solving Quality" and "Students' Academic Performance", along with its influence through "Critical" and "Creative Thinking Skills", Hypotheses 5 faced rejection due to higher *p*-values. Hypotheses 6 and 7 examine the indirect effects of problem-solving quality on students' academic performance through intermediary variables. In Hypothesis 6, it was found that problem-solving quality significantly impacts students' academic performance by enhancing critical thinking skills. This is indicated by an original sample value of 0.536, a T statistic of 6.731, and a p-value of 0.000, which suggests that this effect is highly statistically significant. Therefore, it can be concluded that improving problem-solving quality will enhance students' critical thinking skills, ultimately leading to better academic performance. In summary, this path analysis provided valuable insights into the complex relationships among variables within the context of engineering education. It also clarified which hypotheses were accepted or rejected based on the results of the conducted statistical evaluation.

Problem-solving skills, Critical Thinking Skills, and Creative Thinking Skills were essential elements of higher-order thinking skills crucial in modern education. Problem-solving entailed the ability to analyze complex issues, identify solutions, and make informed decisions. Critical thinking includes evaluating information critically, analyzing it from multiple perspectives, and forming well-reasoned judgments. Conversely, Creative thinking encourages students to think innovatively, generate fresh ideas, and method challenges with unique perspectives. In the realm of technical education, these skills were essential for students' excellence, enabling students to effectively navigate complex problems, devise innovative solutions, and adapt to evolving technological landscapes. The integration of these skills in engineering education not only fosters a deep understanding of the subject matter but also cultivates versatile individuals capable of addressing real-world challenges through multidimensional methods. The incorporation of Problem-Solving, Critical Thinking, and Creative Thinking Skills within education framework recognized the dynamic nature of learning, preparing students for success in an increasingly interconnected and rapidly changing world.

The analysis yielded intriguing and unexpected findings, adding nuance to the understanding of the relationships among the variables in the study. Notably, a strong correlation emerged between creative and critical thinking skills and students' academic performance, diverging from the initial expectation that creative thinking would contribute more significantly. Another noteworthy discovery was the substantial and complex impact of problem-solving skills on students' academic performance, indicating influences beyond the anticipated factors. Additionally, unexpected mediator variables surfaced during the analysis, revealing previously unidentified elements that may mediate or moderate the relationships among the main variables. These findings collectively provide additional insights, highlighting the inherent complexity in the dynamics of thinking skills, problem-solving quality, and students' academic performance in the context of engineering education. They serve as a foundation for further research to delve deeper into the factors influencing these dynamics.

Afterward, through path analysis, the research establishes a significant relationship between creative thinking skills, critical thinking skills, problem-solving quality, and students' academic performance in the context of engineering education. The implementation of AR in education is considered an innovative approach that enhances student engagement and understanding, enriching creative and critical thinking skills, as well as problem-solving abilities. As a result, students can achieve better academic performance. Further discussion on how the specific implementation of AR stimulates the development of higher-order thinking skills and enhances students' academic performance can provide additional insights into the positive impact of this technology in an educational context.

IV. Conclusion

In conclusion, this study underscored the importance of developing higher-order thinking skills in engineering education to address the challenges of the 21st century. The integration of AR technology offered new opportunities to create personalized and interactive learning experiences that supported the cultivation of higher-order thinking skills. Results from SEM analysis showed that critical and creative thinking, as well as problem-solving skills, had a positive impact on students' academic performance. In the context of higher-order thinking skills, critical thinking enables students to analyze problems deeply and formulate informed solutions. Therefore, the cultivation of higher-order thinking abilities, such as creative and problem-solving skills, has become essential elements in producing engineering graduates who are flexible, innovative, and equipped to face the difficulties of a world that is always changing.

This study faced challenges in accurately measuring the impact of AR technology on developing higher-order thinking skills and adjusting evaluation instruments for cognitive aspects. Exploring complex interactions among factors like students' initial abilities, learning styles, and program characteristics proved intriguing. Furthermore, this research provides a significant contribution to the field of technical education by highlighting the crucial role of developing higher-order thinking skills in addressing the challenges of the 21st century. The integration of Augmented Reality (AR) technology emerges as a transformative approach, offering opportunities for personalized and interactive learning experiences that support the development of these essential skills.

For future studies, a deeper exploration of the effectiveness of integrating AR technology to enhance higher-order thinking skills in engineering education is recommended. Focus areas include understanding the interaction between students' learning styles, technological proficiency, and training environments for successfully implementing these skills through AR. Additionally, examining the long-term impact and incorporating qualitative data through interviews or observations would provide richer insights. Interdisciplinary studies could extend the application of this method to other disciplines, fostering a broader implementation of higher-order thinking skills and AR.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Muhammad Anwar: Concept and design, Drafting manuscript, Supervision, Technical and material support. Yuni Rahmawati and Nurhening: Collecting data, Supervision and Statistical analysis. Hendra Hidayat: Statistical analysis and Supervision. Elsa Sabrina: Drafting manuscript, Collecting Data, Statistical analysis. All authors had approved the final version

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