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Research Article

Investigating the impact of augmented reality-integrated project-based learning on university students' creative innovation, computational thinking, and academic resilience

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The development of digital technology has driven a transformation in learning approaches in higher education to support the strengthening of 21st-century skills among students. This study aims to analyze the influence of Augmented Reality-Integrated Project-Based Learning on students' creative innovation, computational thinking, and academic resilience. The research used a quantitative approach with a quasi-experimental design. The sample consisted of sixth-semester students from a teacher education program, selected using purposive sampling. Data were collected through tests, questionnaires, and documentation of student project outcomes. Data analysis techniques used were Multivariate Analysis of Variance and univariate Analysis of Variance to examine the influence of the learning model on each dependent variable. The results showed that the Augmented Reality-Integrated Project-Based Learning model had a significant effect on the combined three abilities, with the greatest contribution to improving academic resilience, followed by creative innovation and computational thinking. The conclusion of this study is that Augmented Reality-Integrated Project-Based Learning is effective in strengthening students' higher-order thinking skills, creativity, and academic resilience in facing the challenges of 21st-century learning.

Keywords: Academic resilience; Augmented reality card; Computational thinking; Creative innovation; Project-based learning

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1. Introduction

Higher education is currently at the center of increasingly complex global challenges, such as digital technology disruption, global economic uncertainty, and ever-changing socio-cultural dynamics (Huang et al., 2023; Saraiva et al., 2021). The advancement of artificial intelligence, automation, and digital transformation across sectors has changed the landscape of the job market and demands universities to not only emphasize theoretical mastery but also prepare students with relevant and applicable life skills (Shin et al., 2021; Zhang et al., 2024). Students in today's contemporary era can no longer be positioned merely as passive entities consuming theoretical knowledge but must be constructed as active subjects capable of responding to changes with cognitive flexibility and sufficient psycho-emotional resilience (Aditama & Setiawan, 2020; Ali et al., 2023; Hadi & Kamarullah, 2024). This necessitates the integrative combination of conceptual

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academic understanding with the mastery of adaptive life skills that respond to multidimensional and cross-sectoral structural changes (Lin et al., 2021).

The pressure of a competitive global world shifts the demand from merely technical performers to innovators capable of formulating valuable breakthroughs (Erşen & Alp, 2024; Salikhova et al., 2020). Creative innovation ability forms a critical foundation for generating applicable ideas in professional, entrepreneurial, and academic research settings, and education must cultivate it to prepare learners for a technology-driven global society (Sarıtiken, 2024). Creative innovation, in this context, refers to the thinking and acting process involving the generation of original ideas, transformation of ideas into relevant products or solutions, and the courage to break from conventional thinking patterns to create sustainable positive impacts (Abidin et al., 2025; Aditama & Setiawan, 2020). Furthermore, this ability plays a strategic role in project-based learning, where students are challenged to identify real-world problems, design multidisciplinary solutions, and produce products that are not only functional but also valuable (Ramadhani et al., 2022). Therefore, creative innovation is not merely an additional competency but an essential prerequisite for producing graduates who can actively contribute to shaping a more progressive and sustainable future (Hadi & Kamarullah, 2024).

Additionally, in line with rapid technological advancements, computational thinking has become one of the essential skills students must possess across various fields of study (Shin et al., 2021). The increasing role of technology in daily life makes computational thinking no longer an exclusive skill for computer science but a cross-disciplinary mindset that strengthens logic in problem-solving (Lin et al., 2021). Computational thinking refers to a systematic approach to understanding and solving problems by breaking them into smaller, manageable units and enabling individuals to design efficient solutions through structured thinking (Angraini & Sthephani, 2024). This skill is not only beneficial for technology or informatics students but is also a valuable asset in supporting systematic thinking in domains such as mathematics, natural sciences, and even technology-based project design (Angraini et al., 2023). Computational thinking enhances students' ability to integrate knowledge, develop logical problem-solving strategies, and produce learning products based on data and innovation (Angraini et al., 2024; Huang et al., 2023; Zhang et al., 2024).

In facing increasingly complex academic life dynamics, students encounter various pressures, including heavier coursework, high social expectations, and challenges due to the shift towards online and hybrid learning models (Johansson et al., 2024). These circumstances demand a strong internal capacity to remain resilient and grow, where academic resilience becomes a crucial psychological foundation for students to continue learning optimally without being easily affected by pressure or failure (Ahmed et al., 2018). Academic resilience can be defined as an individual's ability to manage academic pressure constructively, maintain motivation to learn, and show consistency in achievement despite difficult or disappointing situations (Amoadu et al., 2025). Since the post-pandemic period, with face-to-face learning no longer fully implemented, this ability has become an increasingly key factor determining student success in adapting to flexible yet distraction-filled learning environments (Ye et al., 2021). Students with high levels of academic resilience generally exhibit stronger stress endurance, better adaptive capabilities, and a tendency to complete their studies with satisfying results, even under uncertain conditions (2024; Liaqat et al., 2024; Uicheng & Chobphon, 2024).

21st-century students must master higher-order thinking skills and be able to confront complex realities. Therefore, educators need to apply contextual, experiential, and interactive approaches to create meaningful learning experiences (Fitri et al., 2024). Educators can optimize Project-Based Learning [PjBL] strategies by encouraging students to actively engage in solving real problems so that they can build knowledge through collaborative, explorative, and reflective processes (Atmojo et al., 2025). Educators also need to integrate technology to make learning more adaptive to current developments, particularly through visual enhancement and the presentation of innovative materials (Fatahillah & Faradillah, 2023).

Through the integration of Augmented Reality [AR], educators can enrich PjBL with interactive visualizations that help students understand abstract concepts and create immersive learning experiences (Al-Karablieh, 2020; Huang & Musah, 2024). This study uses marker-based AR in the form of Augmented Reality Cards, allowing educators to present three-dimensional objects to increase student focus, motivation, and engagement during learning (Azi & Gündüz, 2020; Suharti et al., 2024). The use of AR makes learning more dynamic by combining technology, creativity, and problem-solving simultaneously within an integrated learning ecosystem (Du & DeWitt, 2024; Huang & Musah, 2024).

The AR-PjBL model is grounded in several key educational theories that explain how technology can meaningfully support student learning. One of the core frameworks is Vygotsky's socio-cultural theory, which emphasizes the importance of social interaction and collaborative learning. In AR-supported environments, students engage in joint exploration of 3D visualizations, promoting shared understanding through dialogue and cooperation. These interactions allow for effective scaffolding, especially within the zone of proximal development [ZPD] (Jin, 2016). Learners can receive guidance from peers or instructors while engaging with abstract content made concrete through AR. Bandura's theory of self-efficacy also supports the use of AR in learning contexts. Students who succeed in solving problems or completing tasks using AR tools gain mastery experiences that strengthen their belief in their own abilities (Akosah et al., 2025). This increase in self-efficacy leads to greater motivation, persistence, and academic resilience. The immersive and low-risk nature of AR allows learners to experiment, make mistakes, and try again without fear of failure. Additionally, Piaget's Cognitive Theory provides a cognitive explanation for multimedia's effectiveness. The theory posits that meaningful learning occurs when learners process visual and auditory information in an integrated manner (Ahmad et al., 2016). AR, as part of multimedia, combines images, narration, and interactivity to create multi-sensory experiences that enhance attention and understanding. Learners are more likely to retain and transfer knowledge when they engage with content through multiple channels (Alahmad, 2020; Pakpahan & Saragih, 2022).

While most prior studies have examined the effects of Augmented Reality in isolation—typically focusing on enhancing visual perception or improving conceptual understanding in science—this study advances the field by exploring the strategic integration of AR within the Project-Based Learning [PjBL] framework. Such integration remains underexplored, particularly in non-IT higher education settings and among pre-service teachers, who require targeted development of 21st-century competencies. By embedding AR into PjBL, this study aims to create a synergistic learning model that not only leverages the immersive, interactive affordances of AR, but also aligns with constructivist, student-centered pedagogies. Theoretically, the research offers a framework that explains how AR-PjBL environments can foster creativity, computational thinking, and academic resilience through social collaboration, experiential learning, and multi-sensory cognitive engagement. Practically, the study contributes to the design of interactive learning ecosystems that are immersive, adaptive, and aligned with real-world problem-solving. This innovation is expected to support higher education institutions in enhancing graduate quality and accelerating digital transformation. Therefore, the present study fills a significant gap by providing both empirical evidence and conceptual insight into how AR-PjBL can serve as a responsive instructional model for 21st-century learning demands.

2. Method

2.1. Research Design

This study employed a quantitative approach with a quasi-experimental design using the Nonequivalent Control Group Design model. The experimental group received learning through Project-Based Learning assisted by Augmented Reality Cards, while the control group used the Think Pair Share model assisted by textbooks. Both groups were given pre-tests and post-tests to measure changes in Creative Innovation, Computational Thinking, and Academic Resilience. Table

1 summarizes the research design of a study comparing two different instructional approaches on student outcomes.

Table 1
Research Design

Group	*Pre-Test*	*Treatment*	*Post-Test*
Experiment	O_1	Project-Based Learning + AR Card	O_2
Control	O_3	Think Pair Share + Textbook	O_4

Note. O_1, O_3: Pre-test for experimental and control groups; O_2, O_4: Post-test for experimental and control groups.

Augmented Reality was implemented using the Assemblr Edu platform, an educational AR-based application that enables students to create, upload, and scan 3D objects through mobile devices. Students designed AR Cards (Augmented Reality Cards) as products of Project-Based Learning, featuring visual markers that can be scanned to display interactive educational content. The devices used included smartphones (Android/iOS) for scanning and testing, as well as laptops/PCs to access the web-based Assemblr Studio for creating and editing more detailed 3D objects. Students demonstrated a moderate to high level of digital literacy, as reflected in their ability to use the application, understand basic AR concepts, and independently develop digital content after completing a short training session (only four class meetings).

2.2. Participants

The total number of samples in this study was 70 students. The study involved two groups, namely the experimental group and the control group, each consisting of 35 fifth-semester students from the Primary School Teacher Education [PGSD] Study Program. The sampling technique used was cluster random sampling. This technique involves randomly selecting groups or classes rather than individuals. Two existing classes from the current semester were randomly chosen: one class was designated as the experimental group receiving Project-Based Learning assisted by Augmented Reality Cards, and the other as the control group receiving the Think Pair Share learning model assisted by textbooks. Cluster random sampling was chosen because it fits the naturally formed class conditions in a formal educational setting, facilitates administrative management, avoids intergroup contamination, and maintains consistent classroom dynamics to support the validity of the research results. Therefore, caution should be exercised in applying these findings beyond the specific context of this study, and further research with more diverse and representative samples is needed to strengthen external validity.

2.3. Data Collection Techniques

This study employed two data collection techniques: test and non-test techniques. The test technique was used to measure students' creative innovation. The test was performance-based, in which students were asked to produce a prototype in the form of an AR Card (Augmented Reality Card) as a product of the project-based learning activity. The assessment criteria included creativity and innovation in the content and function of the AR Card, as well as the overall quality of project implementation. The assessment was conducted using a performance rubric validated by experts. The detailed performance rubric used to assess students' creative innovation in developing the AR Card is presented in Table 2 and Table 3.

Meanwhile, the non-test technique involved distributing questionnaires to measure the other two variables: computational thinking and academic resilience. The computational thinking questionnaire was designed to reflect students' ability to decompose problems, recognize patterns, create abstractions, and construct problem-solving algorithms, all assessed using a Likert scale. The academic resilience questionnaire was designed to measure the extent to which students could endure and adapt to academic challenges, covering emotional regulation, learning persistence, and self-confidence in academic ability.

Table 2
Assessment Rubric (Creative Innovation)

Assessment Aspect	*Indicator / Assessment Criteria*	*Score Scale*	*Maximum Score*
Idea creativity	Originality and novelty of ideas in the AR Card content	1–5	5
Functional innovation	New functions or innovative use of the AR Card in the learning context	1–5	5
Visual design quality	Appropriateness of the graphic design in terms of content, aesthetics, and user-friendliness	1–5	5
Relevance to learning goals	Alignment of the AR Card product with the learning objectives of the project	1–5	5
Project implementation process	Planning, teamwork, technology utilization, and time management during the project execution	1–5	5

Table 3
Score Interpretation

Total Score	*Innovation Level*	*Description*
21–25	Highly Innovative	Demonstrates excellent originality, function, design, and educational value.
16–20	Innovative	Shows good innovation in idea, function, and design, with minor weaknesses.
11–15	Moderately Innovative	Displays moderate creativity; some aspects need refinement.
6–10	Less Innovative	Lacks sufficient innovation; improvements needed in several areas.
1–5	Not Innovative	Shows minimal creativity or relevance to learning objectives.

The research instruments were tested for validity and reliability. The validity test in this study was conducted through two approaches: content validity and construct validity. Content validity aimed to assess the suitability of each item with the indicators being measured based on theoretical review and expert judgment. Furthermore, construct validity was used to test the coherence among items in measuring the same theoretical construct. Tests were conducted using Aiken's V and item-total correlation analysis, where the correlation value (r calculated) was evaluated.

Table 4
Validity Test

Type of Validity / Instrument	*Testing Technique*	*Test Result*	*Description*
Content Validity			
Creative Innovation Test (AR card)	Expert Judgment	Feasible based on expert review	Valid
Computational Thinking Questionnaire	Expert Judgment	Feasible based on expert review	Valid
Academic Resilience Questionnaire	Expert Judgment	Feasible based on expert review	Valid
Construct Validity			
Creative Innovation Test (AR Card)	Aiken's V	V = 0.85 – 0.94	Highly Valid
Computational Thinking Questionnaire	Item-total Correlation	r = 0.32 – 0.71 (significant)	Valid
Academic Resilience Questionnaire	Item-total Correlation	r = 0.35 – 0.69 (significant)	Valid

The reliability test was conducted to ensure that each instrument used in this study generated consistent and stable data (see Table 5). The performance test for creative innovation was tested using Cohen's Kappa to measure inter-rater consistency, resulting in a score of 0.78, which falls into the high category. This indicates that the assessment of the AR Card product was consistently conducted by the raters. Meanwhile, the computational thinking and academic resilience questionnaires were tested using Cronbach's Alpha to examine internal consistency among the items. An alpha value of 0.82 for computational thinking and 0.80 for academic resilience indicates that both questionnaires have good reliability. Thus, it can be concluded that all instruments in this study met the reliability criteria and can be used to accurately measure the research variables.

Table 5
Reliability Test

Research Variable	*Instrument Type*	*Testing Technique*	*Test Result*	*Description*
Creative Innovation	Performance Test (AR Card product)	Cohen's Kappa	K = 0.78	High Reliability
Computational Thinking	Likert Scale Questionnaire	Cronbach's Alpha	α = 0.82	Reliable
Academic Resilience	Likert Scale Questionnaire	Cronbach's Alpha	α = 0.80	Reliable

2.4. Data Analysis Techniques

Data analysis techniques in this study consisted of descriptive analysis and inferential analysis. Descriptive analysis was used to describe the characteristics of the data for each variable, namely creative innovation, computational thinking, and academic resilience, by presenting the mean, standard deviation, maximum, and minimum values for each treatment group. Subsequently, inferential analysis was conducted to test the effect of project-based learning integrated with augmented reality technology on the three research variables. Before testing the hypothesis, prerequisite tests were conducted, including normality test, homogeneity test, and covariance matrix test (Box's M Test). The normality test was conducted to determine whether the data were normally distributed using the Kolmogorov-Smirnov test, while the homogeneity test was conducted to determine the equality of variances among groups using Levene's test. The covariance matrix test (Box's M Test) was used to determine whether the covariance matrices among groups were homogeneous. After fulfilling the prerequisite tests, hypothesis testing was carried out using Multivariate Analysis of Variance [MANOVA] to examine whether there were significant simultaneous differences in the three dependent variables based on the given treatment. MANOVA was chosen because it is capable of analyzing the effect of treatment on more than one dependent variable simultaneously.

3. Result

3.1. Research Data Description

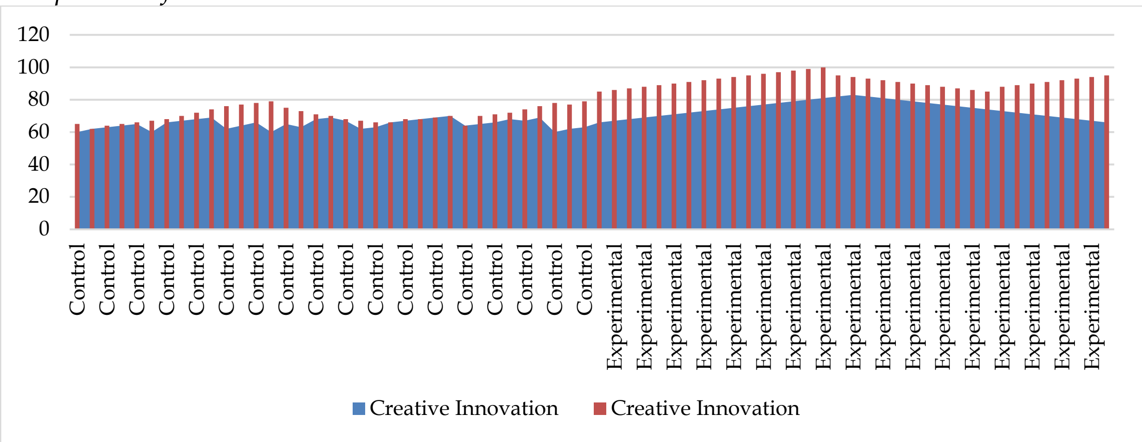
Based on the descriptive statistical results for the three variables, namely Creative Innovation, Computational Thinking, and Academic Resilience, there was a noticeable difference between the pre-test and post-test scores, indicating an improvement in student learning outcomes after the treatment or intervention. The descriptive statistics results of the three variables are summarized in Table 6.

Based on Table 6, it can be seen that the Creative Innovation scores in the experimental group were higher in both the pre-test and post-test compared to the control group, with a more significant increase. The data distribution in the experimental group was wider in the pre-test but more stable in the post-test, reflecting consistent improvement after the treatment. Figure 1 represents the visualization of the comparison between pre-test and post-test data for creative innovation.

Table 6
Descriptive Statistics

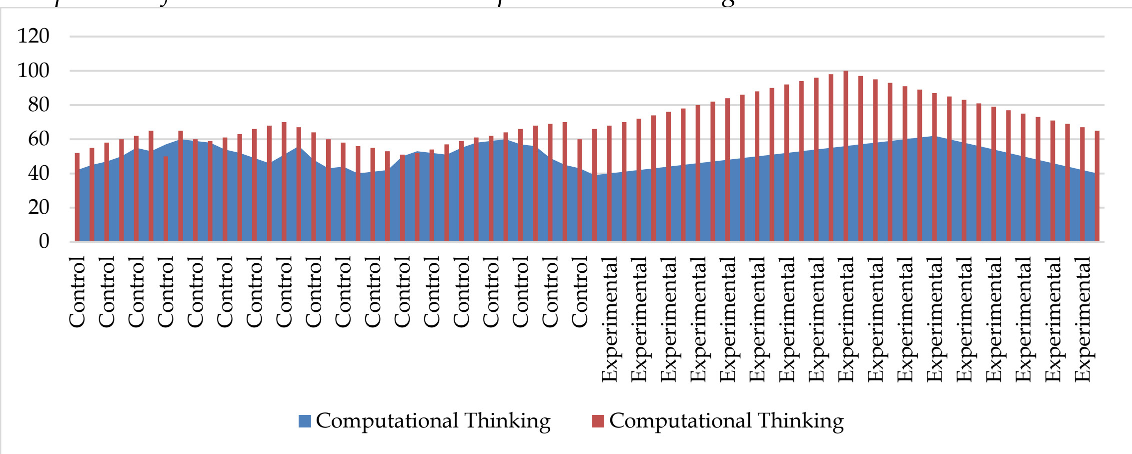
Group and Statistics	*CI_Pre*	*CI_Post*	*CT_Pre*	*CT_Post*	*AR_Pre*	*AR_Post*
Control						
Mean	65.06	70.71	50.86	60.57	71.03	81.60
Minimum	60.00	62.00	40.00	50.00	60.00	70.00
Maximum	70.00	79.00	60.00	70.00	83.00	93.00
Median	65.00	70.00	51.00	60.00	70.00	82.00
Standard Deviation	2.97	4.81	6.07	5.68	6.92	6.49
Experimental						
Mean	74.26	91.49	50.34	82.03	73.26	107.63
Minimum	66.00	85.00	39.00	65.00	65.00	90.00
Maximum	83.00	100.00	62.00	100.00	82.00	125.00
Median	74.00	91.00	50.00	82.00	73.00	108.00
Standard Deviation	5.13	3.96	6.84	10.30	5.13	10.43

Figure 1
Comparison of Pre-test and Post-test Creative Innovation Data



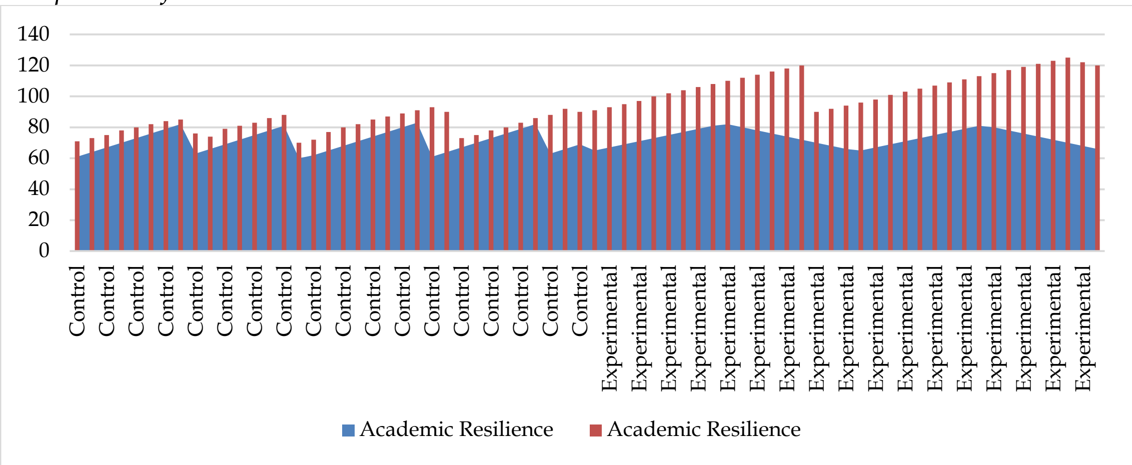
Furthermore, for the Computational Thinking variable, the scores in the experimental group increased sharply from pre-test to post-test compared to the control group, which showed a more moderate increase. Although the initial averages of both groups were almost the same, the experimental group's post-test scores showed a significant jump with a wider data spread. Figure 2 shows the comparison between pre-test and post-test data for computational thinking.

Figure 2
Comparison of Pre-test and Post-test Computational Thinking Data



For the Academic Resilience variable, the experimental group experienced a much greater increase compared to the control group, with a much higher post-test average. Although the initial values of both groups were relatively balanced, the final results showed a strong impact of the treatment on the academic resilience of the experimental participants. Figure 3 shows the comparison between pre-test and post-test data for academic resilience.

Figure 3
Comparison of Pre-test and Post-test Academic Resilience Data



Overall, the data show significant improvements in all three measured aspects: Creative Innovation, Computational Thinking, and Academic Resilience. The increase in the average and median values from pre-test to post-test indicates that the intervention had a positive effect. This reflects the development of students' abilities in innovation, computational thinking, and academic resilience.

3.2. Assumption Testing

The first assumption test conducted was the normality test. This test aimed to determine whether the data obtained from the pre-test and post-test for each variable were normally distributed, thereby determining the appropriate type of statistical analysis to use. This test used the Kolmogorov-Smirnov method with a significance level of 0.05. The normality test results are presented in Table 7.

Table 7
Normality Test Results

Groups and variables	*Time*	*K-S Statistics*	*p*	*Normality*
Control				
Creative Innovation	Pre-Test	0.108	.200	Normal
Creative Innovation	Post-Test	0.114	.187	Normal
Computational Thinking	Pre-Test	0.118	.172	Normal
Computational Thinking	Post-Test	0.121	.160	Normal
Academic Resilience	Pre-Test	0.132	.112	Normal
Academic Resilience	Post-Test	0.129	.124	Normal
Experimental				
Creative Innovation	Pre-Test	0.096	.200	Normal
Creative Innovation	Post-Test	0.088	.200	Normal
Computational Thinking	Pre-Test	0.101	.200	Normal
Computational Thinking	Post-Test	0.095	.200	Normal
Academic Resilience	Pre-Test	0.109	.187	Normal
Academic Resilience	Post-Test	0.103	.198	Normal

Based on the results shown in Table 7, all *p*-values for each variable, in both control and experimental groups, are greater than .05. This indicates that the data for Creative Innovation, Computational Thinking, and Academic Resilience variables before and after treatment are normally distributed. Subsequently, a homogeneity test was conducted, with a summary shown in Table 8.

Table 8
Homogeneity Test Results

Variable	*Stage*	*Levene Statistic*	*df1*	*df2*	*p*
Creative Innovation	Pre-Test	1.254	1	68	.267
Creative Innovation	Post-Test	0.784	1	68	.379
Computational Thinking	Pre-Test	0.912	1	68	.343
Computational Thinking	Post-Test	1.038	1	68	.312
Academic Resilience	Pre-Test	0.876	1	68	.353
Academic Resilience	Post-Test	1.129	1	68	.292

Based on the results of Levene's test, all significance values (p-value) are greater than 0.05, indicating that the data have homogeneous variances between groups (control and experimental) for each variable, in both pre-test and post-test stages. Before conducting MANOVA analysis, it is essential to test the assumption of homogeneity of covariance matrices between groups using Box's M test. This test aims to ensure that the dependent variables (Creative Innovation, Computational Thinking, and Academic Resilience) have equal covariance matrices across groups (control and experimental). Table 9 presents the results of Box's M test for pre-test and post-test data of the three variables.

Table 9
Box's M Test Results

No	*Type of Test*	*Box's M Value*	*F*	*df1*	*df2*	*Sig. (p)*	*Description*
1	Box's M (Pre-Test)	4.326	1.204	6	20491	0.689	Homogenous (*p* > .05) – Assumption met
2	Box's M (Post-Test)	6.750	1.387	6	20491	0.521	Homogen (*p* > .05) – Assumption met

Box's M test was conducted to determine whether the covariance matrices between the groups (control and experimental) for the three variables — Creative Innovation, Computational Thinking, and Academic Resilience — are homogeneous. The test results show that the significance values for both pre-test and post-test are greater than .05. Therefore, it can be concluded that the assumption of covariance matrix homogeneity is fulfilled, and the MANOVA analysis can be continued.

3.3. Hypothesis Testing

The hypothesis testing in this study employed MANOVA. MANOVA was used to examine the influence of one or more independent variables on two or more dependent variables simultaneously. In other words, MANOVA answers whether there is a significant difference across several dependent variables due to a specific treatment. The results of the multivariate statistical test are presented in Table 10, showing that the PjBL model has a significant effect on the three variables simultaneously.

The results of the MANOVA test in Table 10 show that the PjBL learning model significantly influences the combined three dependent variables: Creative Innovation, Computational Thinking, and Academic Resilience, as indicated by the significance values of all four multivariate statistics being below .05. The Pillai's Trace value of 0.615 and Wilks' Lambda of 0.385 indicate a strong

Table 10
MANOVA Test Results of PjBL Model on Creative Innovation, Computational Thinking, and Academic Resilience

Multivariate Statistics	*Value*	*F*	*Error df*	*p*	*Interpretation*
Pillai's Trace	0.615	5.278	68	.001	The PjBL model has a significant effect on the combination of CI, CT, and AR
Wilks' Lambda	0.385	5.278	68	.001	The PjBL model significantly affects the three variables
Hotelling's Trace	2.325	5.278	68	.001	The effect of PjBL is strong on the combination of dependent variables
Roy's Largest Root	2.325	5.278	68	.001	PjBL has a dominant influence on at least one variable

Note. CI: Creative Innovation; CT: Computational Thinking; AR: Academic Resilience.

and consistent effect of PjBL implementation on the overall variables. Meanwhile, the identical values of Hotelling's Trace and Roy's Largest Root (2.325) reinforce the conclusion that the PjBL model contributes dominantly to at least one of the three variables. Table 11 presents the univariate ANOVA test results to examine the effect of PjBL separately on each variable, all of which show highly significant effects with high partial eta squared values.

Table 11
ANOVA Test per Variable (Univariate in PjBL MANOVA)

Dependent Variable	*F*	*df*	*p*	*Partial Eta Squared*	*Interpretation*
Creative Innovation	78.23	1, 68	< .001	0.535	Highly significant
Computational Thinking	60.11	1, 68	< .001	0.469	Highly significant
Academic Resilience	87.56	1, 68	< .001	0.563	Highly significant

The univariate ANOVA test results in Table 11 show that the PjBL model has a highly significant effect on the three variables: Creative Innovation, Computational Thinking, and Academic Resilience, with p-values < .001 for each variable. The high Partial Eta Squared values (ranging from 0.469 to 0.563) indicate that the proportion of variance explained by the PjBL model for each variable is substantial, with the greatest effect observed on the AR variable. Next, the MANOVA test of the TPS model on the three variables was conducted.

Table 12
MANOVA Test Results of TPS Model on Creative Innovation, Computational Thinking, and Academic Resilience

Multivariate Statistics	*Value*	*F*	*Error df*	*p*	*Interpretation*
Pillai's Trace	0.142	1.302	68	.120	The TPS model does not significantly affect the combination of CI, CT, and AR
Wilks' Lambda	0.858	1.302	68	.200	The TPS model does not significantly affect the three variables
Hotelling's Trace	0.165	1.302	68	.070	The influence of TPS on the combination of variables is low and near significance
Roy's Largest Root	0.121	2.003	68	.030	There is possibly one variable significantly affected by TPS

Note. CI: Creative Innovation; CT: Computational Thinking; AR: Academic Resilience.

The MANOVA test results in Table 12 indicate that the TPS learning model does not provide a significant effect on the combination of Creative Innovation, Computational Thinking, and Academic Resilience variables, as reflected by p-values > .05 in almost all multivariate statistics, except for Roy's Largest Root, which suggests a potential influence on one variable. The univariate ANOVA test was continued to examine the effects on each variable individually.

Table 13
ANOVA Test per Variable (Univariate in TPS MANOVA)

Dependent Variable	*F*	*df*	*p*	*Partial Eta Squared*	*Interpretation*
Creative Innovation	2.15	1, 68	.147	0.031	Not significant; the effect of TPS on CI is very weak
Computational Thinking	1.88	1, 68	.175	0.027	Not significant; the effect of TPS on CT is very weak
Academic Resilience	3.09	1, 68	.083	0.044	Nearly significant; the effect of TPS on AR is weak

The effect of Think Pair Share on Creative Innovation and Computational Thinking is not significant, with *p*-values above .1 and very weak effects (partial eta squared below 0.05). The effect on Academic Resilience is nearly significant, with a *p*-value approaching .05 and still a weak effect (partial eta squared around 0.04). In general, the effect of Think Pair Share on the three variables is classified as small to very small.

4. Discussion

4.1. The Impact of Augmented Reality-Integrated Project-Based Learning on Students' Creative Innovation

The MANOVA test results indicated that the Project-Based Learning model had a significant effect on the combined three dependent variables, including Creative Innovation. Furthermore, the univariate ANOVA results revealed that the PjBL model had a highly significant influence on Creative Innovation, indicating that the proportion of variance explained by the PjBL model in relation to Creative Innovation was substantial. AR-integrated PjBL offers authentic and concrete learning experiences that encourage students to develop creative ideas through active interaction with both virtual and real-world environments. When Augmented Reality is integrated into project-based learning tasks, students experience creative stimulation through engaging and relevant challenges. AR serves as an external stimulus that activates the senses, particularly visual and auditory, leading to sensory activation. The immersive experience enables students to process the input into symbolic representations in their minds. These representations encourage them to connect, reorganize, and reinterpret information, ultimately resulting in the generation of novel combinations—the foundation of creativity and innovation.

This is supported by Constructivist Theory, which posits that knowledge is actively constructed by individuals through direct interaction with their environment and real experiences, rather than acquired passively (Bodner, 1986; Daodu et al., 2024). AR-integrated PjBL serves as a platform for students to experience, test, and reflect on new ideas, thus fostering the emergence of creative innovation. This is in line with Experiential Learning Theory, which states that effective learning occurs through a cycle of direct experience, reflection, conceptualization, and active experimentation (Kolb & Kolb, 2012).

Hidayat et al. (2023) asserted that PjBL stimulates creativity because students are required to collaboratively solve real-world problems. The integration of AR expands the exploratory space, thereby sharpening students' creativity. This is consistent with Huang and Musah (2024), who emphasized that AR supports spatial understanding and the interactive manipulation of virtual objects, which triggers creative ideas that are difficult to obtain through traditional media. Furthermore, Fitri et al. (2024) stated that PjBL enhances motivation and creativity through authentic challenges that require innovation to solve. AR, as part of PjBL, adds an element of novelty that triggers higher innovation (Abidin et al., 2025).

This finding is supported by Hadi and Kamarullah (2024), who concluded that Augmented Reality systems within Project-Based Learning scenarios significantly promote students' creativity and problem-solving skills. This occurs because the interactive, simulation-based learning experiences provided by AR offer concrete representations of abstract concepts and create opportunities for students to experiment, innovate, and test their hypotheses in realistic situations (de Barros et al., 2025; Ramadhani et al., 2022). In line with this, Febianti et al. (2023) also reported that implementing AR in inquiry-based learning, such as the Questioning-Inquiry Model Strategy, significantly enhances students' critical thinking and knowledge creation. This improvement is closely related to students' creative innovation abilities, as they are encouraged to ask questions, formulate solutions, and construct new understanding independently through active exploration in AR-based learning environments (Crisolo et al., 2021).

Furthermore, Hidayat et al. (2023) noted that integrating AR with STEAM (Science, Technology, Engineering, Arts, and Mathematics) and the PjBL approach leads to significant improvement in learning outcomes and student innovation, particularly in technical education. This multidisciplinary collaboration provides opportunities for students to develop innovative products that require not only theoretical understanding but also the ability to integrate various fields of knowledge in solving real-world projects. This aligns with the findings of Abidin et al. (2025), which showed that using AR combined with collaborative learning strategies and gamification elements enhances students' creativity, teamwork, and intrinsic motivation during project implementation. Learning environments that emphasize engaging and challenging experiences have proven effective in motivating students to think outside the box, refine new ideas, and persevere through obstacles in the learning process (Alshammari & Thomran, 2023; Hidajat, 2023).

4.2. The Impact of Augmented Reality-Integrated Project-Based Learning on Students' Computational Thinking

The MANOVA results showed that the PjBL model had a significant effect on the combination of the three dependent variables, including Computational Thinking. This finding is reinforced by the univariate ANOVA results, which indicated that PjBL contributed significantly to the development of CT, with a p-value $< .001$ and a Partial Eta Squared value of 0.469. This proportion of variance shows that nearly half of the improvement in students' CT abilities can be attributed to the implementation of PjBL. When Augmented Reality is integrated into project-based learning, students are immersed in problem-based contexts that require active exploration and decision-making. This process begins with problem representation, where AR visualizations help students understand abstract problems in concrete ways. As they interact with virtual content, data interpretation is supported by real-time feedback and layered information, enabling them to analyze patterns and relationships. This leads to algorithmic thinking, as students plan and sequence logical steps to solve project tasks. Throughout the process, abstraction is developed when students filter essential information from complex AR environments to focus on relevant variables. Finally, students engage in automation and evaluation, where they test, refine, and reflect on their solutions, forming a complete cycle of computational thinking development grounded in immersive, experiential learning.

PjBL provides a structured set of activities that encourages students to process complex information in depth through real-world projects, thus supporting the reinforcement of CT. This finding is relevant to Information Processing Theory, which posits that effective learning occurs when individuals actively process information through cognitive stages such as attention, encoding, storage, and retrieval (Brayadi et al., 2022). Students' active involvement in decision-making, strategic planning, and project completion within PjBL increases intrinsic motivation, which in turn strengthens their computational thinking skills. Based on this, the Cognitive Apprenticeship Model is also relevant, as it emphasizes that complex thinking skills such as CT can be optimally developed when students learn through guided participation in real-world tasks, as found in PjBL (Beena & Asha, 2023; Brayadi et al., 2022).

Saraiva et al. (2021) argued that computational thinking skills can be built through creative activities involving the production of technology-based real products. This is supported by Shin et al. (2021), who highlighted that CT develops when students are given opportunities to design, test, and revise solutions in authentic contexts. Additionally, Lin et al. (2021) emphasized the importance of student engagement in design-based learning to sharpen CT dimensions such as decomposition, pattern recognition, and algorithmic thinking

This finding also aligns with various empirical studies. For example, Zhang et al. (2024) showed that implementing PjBL in the field of information technology positively contributes to CT development, as students are trained to identify core problems, design algorithm-based solutions, and apply them systematically in real-world situations. Meanwhile, Angraini et al. (2024) concluded that technology-based PjBL encourages students to develop problem decomposition, pattern recognition, and abstraction skills, which are the foundations of CT. They found that students' engagement in collaborative, technology-based projects enhance higher-order thinking skills, including creative and logical problem-solving (Huang et al., 2023). The study by Shin et al. (2021) further confirmed that students who undergo technology-integrated PjBL exhibit significant development in logical thinking, algorithmic reasoning, and the ability to revise solutions iteratively compared to those receiving conventional lecture-based learning.

4.3. The Impact of Augmented Reality-Integrated Project-Based Learning on Students' Academic Resilience

The MANOVA test in this study revealed that the Augmented Reality-Integrated Project-Based Learning model significantly influenced the combination of three dependent variables, one of which was Academic Resilience. Furthermore, the univariate ANOVA results showed that PjBL played a crucial role in strengthening students' academic resilience, with a p-value $< .001$ and a Partial Eta Squared value of 0.563. This was the highest contribution among the variables studied. The magnitude of this variance proportion reflects that AR-integrated PjBL is a highly effective learning strategy for developing students' academic resilience. When Augmented Reality is integrated into project-based learning, students face meaningful challenges that stimulate their persistence and adaptability. The process begins with emotional engagement, as the immersive AR environment captures interest and reduces initial learning anxiety. Through task ownership and responsibility, students actively explore content, make decisions, and solve problems, which cultivates a sense of control over their learning. As they encounter difficulties, the interactive feedback and visual cues from AR support self-regulation and perseverance. This is followed by reflective learning, where students analyze their progress and develop coping strategies. Over time, these experiences reinforce adaptive learning behaviors, such as sustained effort, confidence in facing setbacks, and the ability to bounce back from failure—core aspects of academic resilience developed through continuous, supportive, and meaningful engagement.

Augmented Reality-Integrated PjBL, with its emphasis on exploratory freedom and direct interaction with digital and real-world contexts, supports the fulfillment of all three needs, thereby enhancing students' resilience in facing academic pressures. This is supported by Self-Determination Theory, which highlights the importance of fulfilling the needs for autonomy, competence, and relatedness to promote internal motivation (Salikhova et al., 2020). AR-PjBL enables students to confront learning challenges within complex projects while offering opportunities to achieve mastery experiences that build self-efficacy. This is consistent with Cognitive Theory, which explains that resilience is developed through successful experiences in overcoming challenges (Alahmad, 2020).

According to Uicheng and Chobphon (2024), academic resilience is closely associated with students' ability to manage academic stress through adaptive strategies, and project-based learning models strongly support the creation of such learning environments. Ramadhani and

Sagita (2022) stated that integrating immersive technologies like AR in learning not only enhances interest but also provides meaningful experiences that strengthen students' resilience to academic failure. Additionally, Rahmah and Meiliyandrie (2023) emphasized that resilience does not develop in isolation but is influenced by the social and cultural learning context. The collaborative and hybrid nature of AR-PjBL provides a strong medium for fostering resilience in higher education (Ali et al., 2023).

This finding is also consistent with previous studies that affirmed the effectiveness of Augmented Reality-Integrated Project-Based Learning in developing students' academic resilience. Rahmah and Meiliyandrie (2023) reported that the use of AR in project-based learning not only increased students' perseverance in completing complex tasks but also encouraged them to focus and take initiative in solving problems, due to their heightened emotional and cognitive engagement compared to conventional learning models. The study by Huang and Musah (2024) further strengthened this evidence by showing that AR's real-time visual feedback plays a crucial role in fostering persistence. This feedback allows students to immediately recognize mistakes or successes, thereby promoting self-correction and reducing discouragement in the face of academic obstacles (Aydın & Mutlu, 2023). Meanwhile, Azi and Gündüz (2020) found that the application of technology-based PjBL, including AR, effectively equips students with the skills to constructively deal with failure. This is because students are actively involved in the full learning cycle—from planning, project implementation, to evaluation and reflection—which not only hones technical skills but also reinforces adaptive mindsets and resilience in facing dynamic academic challenges (Suud et al., 2024).

In contrast, the Think-Pair-Share group showed only a nearly significant improvement in academic resilience, indicating a weak effect. This might be due to the limited metacognitive support and less structured peer collaboration inherent in TPS activities. To enhance academic resilience through the Think-Pair-Share strategy, its integration with well-designed textbooks must go beyond surface-level interaction. First, textbooks should include structured prompts that explicitly stimulate metacognitive thinking—such as reflective questions, problem-solving steps, and self-assessment checklists—that students respond to during the "Think" phase. In the "Pair" stage, collaboration can be deepened by guiding students to compare reasoning, justify answers using textbook concepts, and challenge each other's interpretations based on textual evidence. During the "Share" stage, classroom discussions should be facilitated to highlight diverse thinking paths and coping strategies when facing complex academic challenges (Mundelsee & Jurkowski, 2021). The textbook content itself should be inclusive, contextually relevant, and tiered in difficulty to foster a sense of mastery and gradual growth.

5. Conclusion

Based on the results and discussion of the study, several conclusions can be drawn. First, the Project-Based Learning model integrated with augmented reality technology has been proven to exert a positive and significant influence on students' creative innovation, computational thinking, and academic resilience. Second, the implementation of PjBL substantially contributes to strengthening these three competencies, with the most prominent impact observed on academic resilience, followed by creativity and systematic thinking skills. Third, meanwhile, the Think-Pair-Share learning model did not show a significant effect on the combination of those competencies, although there were indications of its contribution to one of the aspects. Thus, it can be generally concluded that technology-enhanced, real-world project-based learning is more effective than Think-Pair-Share in supporting the development of character, thinking skills, and creativity in the context of 21st-century education.

6. Implication

The findings of this study imply that the application of augmented reality-integrated PjBL deserves to be considered a primary alternative in designing learning in higher education, particularly for improving students' creativity, computational thinking, and academic resilience. This approach enriches students' learning experiences through the integration of technology that allows for deeper exploration of ideas. Lecturers and educators are expected to adopt this learning model to better prepare students for the complex challenges of the real world. In addition, the findings provide input for curriculum development to place greater emphasis on project- and technology-based learning. Educational institutions may consider investing in AR infrastructure to support the effective implementation of PjBL. This study also encourages the strengthening of student collaboration within authentic and meaningful learning environments.

Future research should be expanded to increase the relevance and applicability of the findings. Studies could involve different populations, such as students from other universities, academic levels, or cultural backgrounds, to explore broader generalizability. Additional variables—such as student motivation, self-efficacy, or digital literacy—could be examined to gain deeper insights into the mechanisms that influence learning outcomes. Employing qualitative or longitudinal methods may also help capture long-term impacts and provide richer descriptions of students' experiences. Moreover, implementing AR-integrated PjBL in primary or secondary school contexts could reveal its effectiveness across various educational levels and inform policies for early integration of innovative learning technologies.

Declaration of interest: The author declares that no competing interests exist.

Data availability: The data that support the findings of this study are available from the corresponding author upon reasonable request and subject to approval.

Ethical declaration: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Universitas Bina Bangsa (protocol code 2025/IRB-032 and date of approval: 12 June 2025). Informed consent was obtained from all subjects involved in the study.

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