Revolutionizing Learning: Unleashing the Power of Technology Gamification-Augmented Reality in Vocational Education

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***Abstract* – This study explores innovative approaches to enhance vocational education by employing Gamification and Augmented Reality (GAR) in problem-based learning. Utilizing the Borg and Gall development model with a pre-post-experiment design, vocational students constitute the primary subjects. The experimental group experiences Problem-Case teaching enriched with GAR, while the control group relies on traditional learning media. Results indicate a positive impact on student engagement and motivation in the experimental group, attributed to gamification elements and augmented reality. Gamification components, including points and challenges, incentivize active student participation. Augmented reality promotes engaging learning activities and nurtures imaginative and analytical thinking skills. This research enhances understanding of vocational education and proposes a comprehensive learning approach using sustainable gamification and augmented reality technology for industry advancement.**

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Educators can benefit from these findings when formulating policies and curricula to enhance the overall quality of vocational education.

***Keywords*– Augmented reality, classroom interactivity, gamification, problem-case method, TVET.**

1. Introduction

Vocational education encounters fresh challenges in developing human resources adept at thriving in a digitalized environment [1], [2], [3], [4]. The challenges and responsibilities of vocational education are vital, requiring the production of graduates possessing skills aligned with industry demands [5]. Vocational graduate students need academic and technical skills, including critical and creative problem-solving skills. Developing thinking skills, particularly critical and creative thinking, is essential in 21st-century education [6].

However, according to a study by the Martin Prosperity Institute for the Global Creativity Index 2015, Indonesia ranked 115th out of 139 countries [7]. Conducted by Hans Jellen from the University of Utah and Klaus Urban from the University of Hannover, the research focused on eight countries, highlighting that student creativity in Indonesia was the least pronounced [8]. The study attributes this to an insufficiently supportive environment, particularly within families and schools, as the primary factor contributing to the low creativity level among Indonesian adolescents. While the Ministry of Education endorses the case method in universities, its current implementation requires effective enhancement of cognitive abilities. However, its limited technology integration makes it less relevant to 21st-century education [9], [10].

The proposed solution integrates the problem-case method with gamification-augmented reality (GAR).

This proposed solution stems from an assessment of anticipated advantages for efficient implementation. The Ministry of Education advocates for the case method, derived from problem-based learning, as a recommended approach [11]. Recent evidence suggests that problem-based learning enhances students' critical and creative thinking abilities [12]. Moreover, incorporating augmented Reality (AR) into the problem-case method was chosen due to its demonstrated enhancement of students' skill abilities [13]. Gamification is justified by the over 20% increase in video game users from 2017 to 2020 [14]. Though not everyone may participate in gaming, its components induce enjoyment and improve concentration. The limited efficacy of the case method in enhancing cognitive abilities and its lack of technology integration diminishes its relevance to 21st-century education. Technology in education effectively captures students' attention [15]. The preferred method is the problem-case approach, known for enhancing cognitive abilities. Past research suggests incorporating technology into education motivates and engages students, improving cognitive skills [16].

This research innovatively integrates GAR with the problem-case method, offering students an engaging and meaningful learning experience. The approach aligns with 21st-century learning, combining digital learning and technology to harness the benefits of the digital era. Computer technology supports various aspects of human labor, including educational initiatives. Consequently, it is crucial to explore the development of gamification-augmented reality (GAR) when optimizing the problem-case method to enhance classroom interactivity and refine students' critical and creative thinking skills. The research aims to advance gamification-augmented reality (GAR) to optimize the implementation of problem-case methods, thereby improving classroom interactivity and fostering students' critical and creative thinking skills.

2. Problem Case Method Integrated with Gamification-Augmented Reality Technology

21st-century learning emphasizes digital lifestyles, thinking skills, inquiry-based learning, and knowledge operations [17].

Three 21st-century curricula align with vocational education: vocational knowledge, thinking tools, empowerment, and digital lifestyle [18]. The information way of working involves collaborating in diverse settings and with various tools. Empowering thinking tools entails proficiency in using digital technologies, tools, and services. Digital lifestyle encompasses embracing and adapting to the digital age [19].

Integrate 21st-century and Industry 4.0 skills into vocational training involving education units, students, teachers, and the learning system [20]. Implement a student-centered learning system (SCL) as a strategy, positioning students as active, independent learners. SCL fosters psychological conditions akin to adult students, enhancing their responsibility and strengthening critical and creative thinking skills. SCL recognizes that learning extends beyond the traditional classroom setting [21]. Numerous SCL learning models exist in problem-based learning, and case methods, recommended by Kemdikbutristek for addressing Industrial Revolution 4.0 and 21st-century challenges, constitute a student-centered model. PBL hones authentic problem-solving skills through real-life scenarios, promoting higher-order thinking [22].

The problem-based learning paradigm is a student-centric methodology that efficiently engages students with proficient feedback mechanisms [23]. The main aim of problem-based learning is to enhance the application of knowledge, problem-solving, and intellectual skills. Recent studies have highlighted its effectiveness in developing targeted competencies and promoting creative and critical thinking abilities [24], [25]. Consequently, integrating gamification augmented reality (GAR) with the problem-case method is an innovative approach with the potential for remarkable changes. Previous research indicates gamification and AR's motivating and achievement-positive advantages [26], [27].

Methodology

This study utilized a research and development (R&D) methodology based on the theory [28].

2.1. Research Type and Development Procedures

The development model chosen is a comprehensive, precise, and systematic procedure aligned with the research's underlying problems. The adopted model is streamlined into four phases to address specific development requirements.

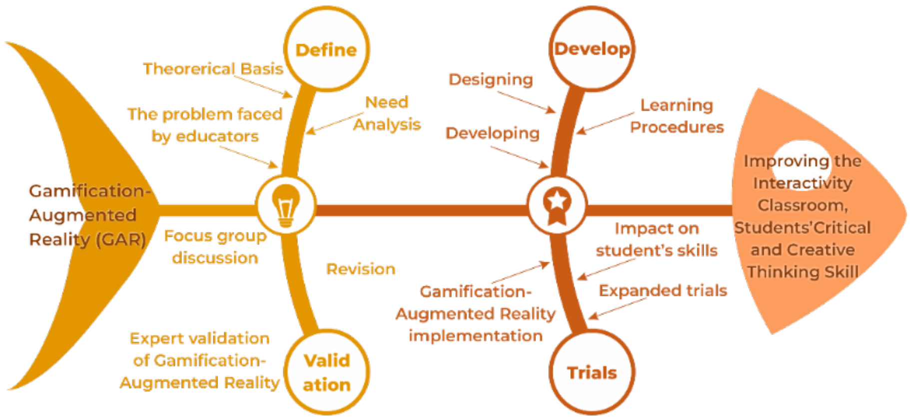

Figure 1. Fishbone Diagram of Research

2.2. Population and Sampling

The sample size for the study was derived from the demographic and numerical attributes of the population, encompassing all undergraduates in Mechanical Engineering Education at Universitas Negeri Padang registered for Basic Electrical and Electronics Engineering courses, totaling 120 individuals. A sample size of 60 students was selected using a simple random sampling method, chosen for its equal opportunity provision for all population members. The sample selection technique employed was proportional random sampling, utilizing the proportional allocation formula [29].

$$n_i = \frac{N_i}{N} x\, n$$

Table 1 outlines the sample obtained in this study using the abovementioned equation.

Table 1. Research sample

No.	Group	Total Population	Sample Calculation	Sample Quantity
1.	BEME A	30	(30/120) x 60	15
2.	BEME B	30	(30/120) x 60	15
3.	BEME C	29	(29/120) x 60	14
4.	BEME D	31	(31/120) x 60	16
	Total	120		60

The 60-person sample will be divided into control and experimental groups. The experimental group will use GAR for learning, while the control group will follow conventional methods.

2.3. Research Instrument

This study employed four key instruments to gather research data: the GAR validity instrument, classroom interactivity, critical thinking, and creative thinking skills.

These instruments utilized 4-point and 5-point Likert scales. A pilot study validated and established the reliability of these instruments before their use in the research data collection.

2.4. GAR Validation Instrument

The GAR validation instrument encompassed expert evaluations across various dimensions of the GAR. The adaptation of this instrument comes from the following researchers [30], [31], which assesses the GAR's construction and technical term aspects. Table 2 describes the validation instrument in detail.

Table 2. Indicators of the GAR validation instrument

Assessment Aspect	Indicators
Construction Term	This GAR Media systematically presents its content.
	GAR user interface is simple, clear, and easy-to-understand sentences.
Technical Term	GAR is user-friendly, stand-alone, self-instructional, self-contained, and adaptive.
	It showcases clear and appealing animations related to GAR.
	Including text and animation enhances the comprehensibility of the instructional content for students.
	This GAR interface is attractive.

2.5. Classroom Interactivity Instrument

The classroom interactivity instrument, adapted from Beauchamp and Kennewell [32], evaluates pedagogical and technological interactivity in education. Given the growing use of new technologies in classrooms, the study explores the correlation between interactive teaching and technology, as depicted in Table 3.

Table 3. Indicators of classroom interactivity instrument

Aspects	Indicators
Authoritative interactivity	Students may use tutorial software.
Dialectic interactivity	Students' use of ICT shifts from a reactive to a constructive style.
Dialogic interactivity	The student has significant influence over the activity direction within the constraints of the provided software and their proficiency in using it.
Synergistic interactivity	Students participate in independent and reflective activities in a collective whole-class setting, collaboratively organizing elements. They select ICT tools to structure their thoughts, guided by the teacher and fellow students.

2.6. Critical and Creative Thinking Skills Instrument

The Association of American Colleges and Universities adopted the critical and creative thinking instrument in this study. The aim is to identify how students generate new ideas, analyze problems, and devise solutions. Table 4 presents detailed information on the instruments for critical thinking and creative thinking skills.

Table 4. Indicators of critical and creative thinking skills instrument

Skills	Indicators
Critical Thinking Skill	Explanation of issues
	Evidence (The utilization of information to examine a particular perspective or conclude).
	The study examines the impact of context and underlying assumptions.
	Student's position (hypothesis/ thesis, perspective)
	The conclusions, along with the associated results, implications, and consequences, are discussed in detail.
Creative Thinking Skills	Generate novel and valuable ideas.
	Elaborate, refine, analyze, and assess their ideas to enhance and optimize creative endeavors.
	Formulate, develop, execute, and proficiently convey new ideas to others.
	Demonstrate receptivity to varied perspectives and be responsive to new ideas; integrate group input and feedback into the collaborative effort.

2.7. Pilot Study

Before the primary research activity, a pilot test assessed the validity and reliability of the research instrument.

The pilot involved a small representative sample of 35 individuals, distinct from the primary research sample. Validity analysis employed the intraclass correlation coefficient (ICC), deemed valid with a coefficient exceeding 0.500. Reliability was assessed using Cronbach alpha [33], [34].

Table 5. Pilot Study Analysis Results

Instruments and Type		Answer	ICC	Cronbach's alpha
GAR Validation Instrument	Questionnaire	Strongly agree (5) to strongly disagree (1) on a 5-point Likert scale	0.829	0.602
Classroom Interactivity Instrument	Rubric	On a 5-point Likert scale, very often (5) equals never (1).	0.715	0.701
Critical Thinking Skill Instrument.	Rubric	Strongly agree (5) to strongly disagree (1) on a 5-point Likert scale	0.716	0.716
Creative Thinking Skills Instrument	Rubric	Strongly agree (5) to strongly disagree (1) on a 5-point Likert scale	0.742	0.605

2.8. Treatment Procedures

The experimental group implemented the problem-case method and integrated GAR into their learning approach. Conversely, the control group used a conventional approach to learning.

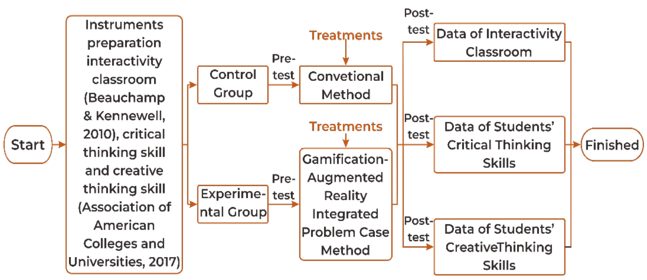

Figure 2. Problem-case method Integrated GAR Procedure

2.9. Problem-Case Method Integrated GAR

The experimental group underwent a pre-test one week before treatment. Subsequently, they received the problem-case integrated GAR method for ten weeks. The post-test in week 11 utilized the same instrument as the pre-test: the classroom interactivity instrument and critical and creative thinking skills.

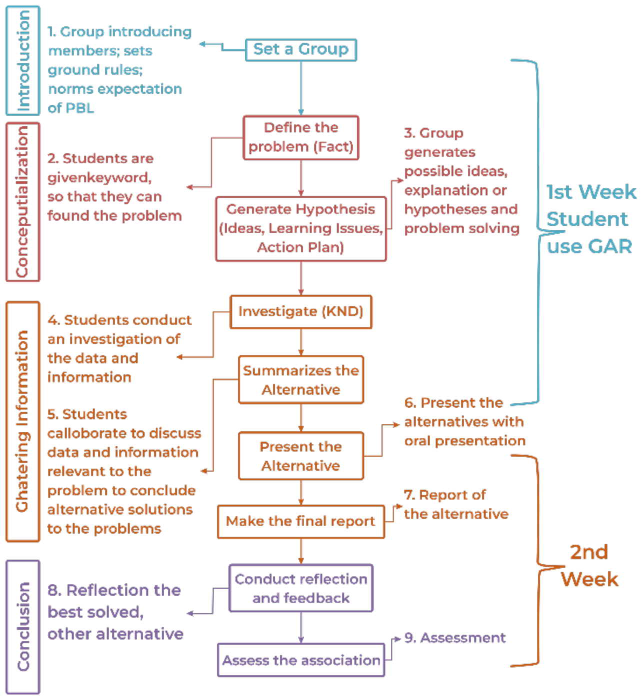

Figure 3. Problem case method integrated with Gamification-augmented reality technology

The problem-case method integrated GAR is implemented in two-week cycles, with 90 minutes of learning per week. In 10 minutes, the teacher introduces the objectives, motivates, and explains the learning procedure. The core learning activity, spanning 70 minutes, involves dividing students into groups, providing GAR software with problems, and engaging in brainstorming and group discussions for 35 minutes. Subsequently, students spend the next 35 minutes completing reports. In the last 10 minutes, the closing activity includes the teacher summarizing the learned material and outlining the next activity plan. The following week, students present the results of the previous week's problem-solving report.

2.10. Conventional Approach

The control group employed a conventional approach with linear and teacher-centered learning procedures. Students primarily receive information through didactic lectures, homework assignments, and written examinations. This traditional approach involves active listening, textbook reading, and adherence to a predefined learning schedule, emphasizing memorization and repetition for information retrieval.

2.11. Data Analysis Technique and Hypothesis Development

This study employed quantitative methods, including percentage, average, standard deviation, and parametric statistics.

Aiken's V coefficient assessed validity, with results ranging from 0 to 1; a value exceeding 0.6 was considered highly valid. Hypothesis testing utilized the t-test and ANCOVA. The study's hypotheses are as follows:

H01: No significant difference is observed in mean scores of classroom interactivity between pre-test and post-test.

H02: No significant difference is found in mean scores of students' critical thinking skills between pre-test and post-test.

H03: No significant difference is identified in mean scores of students' creative thinking skills between pre-test and post-test.

H04: No significant difference exists between the control and experimental groups' mean scores of classroom interactivity.

H05: No significant difference between the control and experimental groups is present in the mean scores of students' critical thinking skills.

H06: No significant difference between the control and experimental groups is evident in the mean scores of students' creative thinking skills.

H07: No significant gender-related differences exist in mean scores of classroom interactivity and students' critical and creative thinking skills between the control and experimental groups.

3. Results and Discussion

Define: The test subjects in this study were students aged 18 to 21, entering adolescence. This age group experiences a career exploration period characterized by a preference for contrasting but not flashy colors and an affinity for music with soft rhythms and harmonies [35]. Additionally, students in this age range love engaging characters and animated images. Integrating color, music, and student creativity in learning can enhance motivation in the educational process [36]. Encouragement and motivation, possibly through specific media, are essential to capture their attention and facilitate learning [38].

Basic electrical and electronic engineering is treated as a course due to curriculum analysis [41], [42], [43]. Traditional teaching methods, such as lectures or rote memorization, are ineffective. Supplementary resources like multimedia with realistic animations are required for a deeper understanding. For students aged 18-21, engaging and innovative methods, like GAR, are more effective than traditional approaches. GAR aids in understanding abstract material and optimizing the problem-case method through real problem-solving.

Develop: At this stage, combining gamification with augmented reality (AR) involves strategic steps to create an engaging user experience. Designing augmented reality gamification requires careful consideration for an engaging, rewarding, and effective user experience. Student interaction with augmented reality gamification incorporates AR technology to deliver a fun, educational, or entertaining experience [44]. Students can engage with gamification elements linked to real-world physical objects or markers. Using the device's camera to focus on a book or poster can activate augmented reality elements associated with gamification [45].

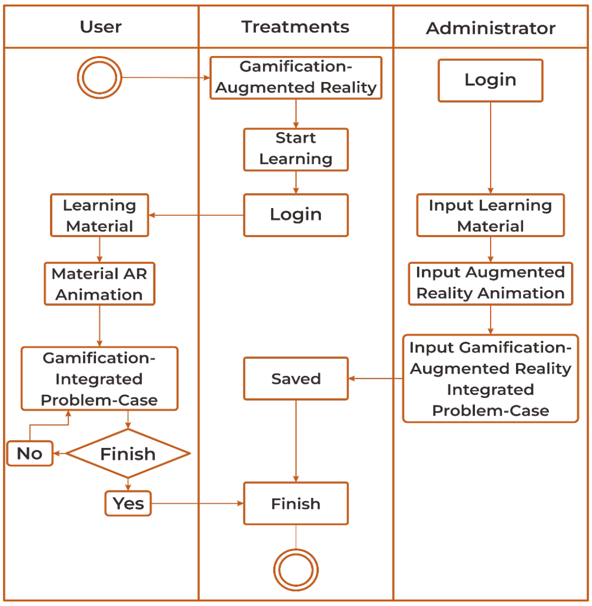

Figure 4. Activity Diagram of Design of GAR

This research utilizes activity diagrams for augmented reality gamification design, serving various functions such as describing user interactions, gamification systems, and augmented reality technology processes. These diagrams aid in understanding application workflows, enhancing communication, and addressing potential issues [46]. Specifically, activity diagrams in this study focus on process description, visualizing workflows, decision modeling, activity synchronization, error identification and handling, modeling iteration, understanding asynchronous processes, and responsiveness to user input. They contribute to comprehensive design understanding, effective communication, and error prevention in developing gamification-augmented reality.

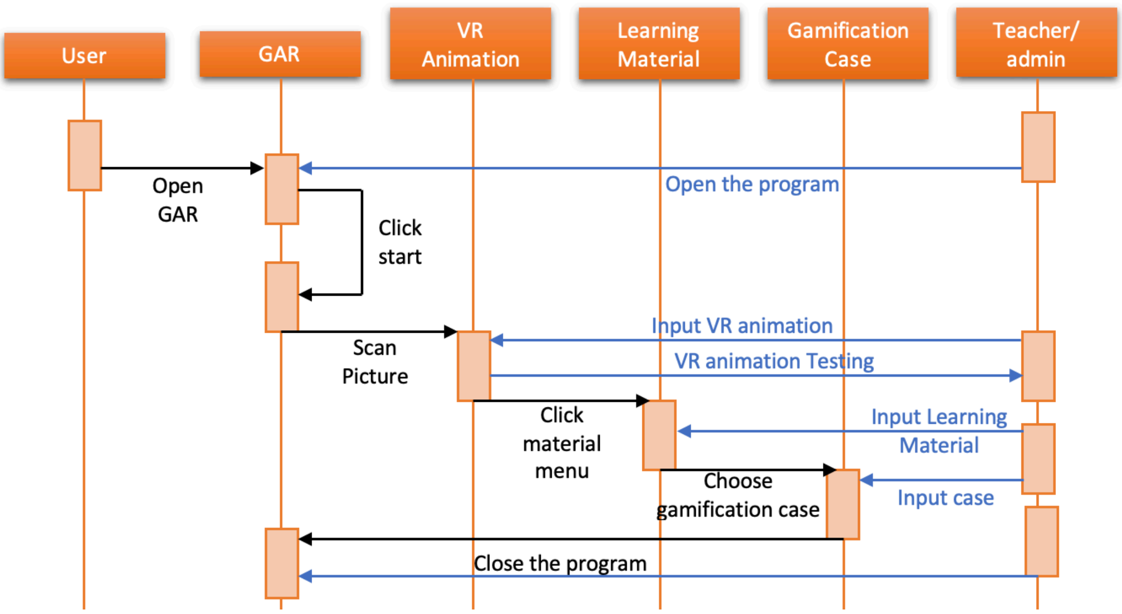

Figure 5. Sequence diagram of design of gamification-augmented reality

The Sequence diagram in the gamification-augmented reality design serves crucial functions, primarily visualizing the interaction flow. This diagram illustrates the sequence of steps and interactions among users, gamification elements, and augmented reality technology, enhancing comprehension of their interactions. It provides insights into the application's workflow, system responses to user input, and the seamless integration of gamification elements and augmented reality technology. Following the diagram's design, a prototype for the GAR was developed.

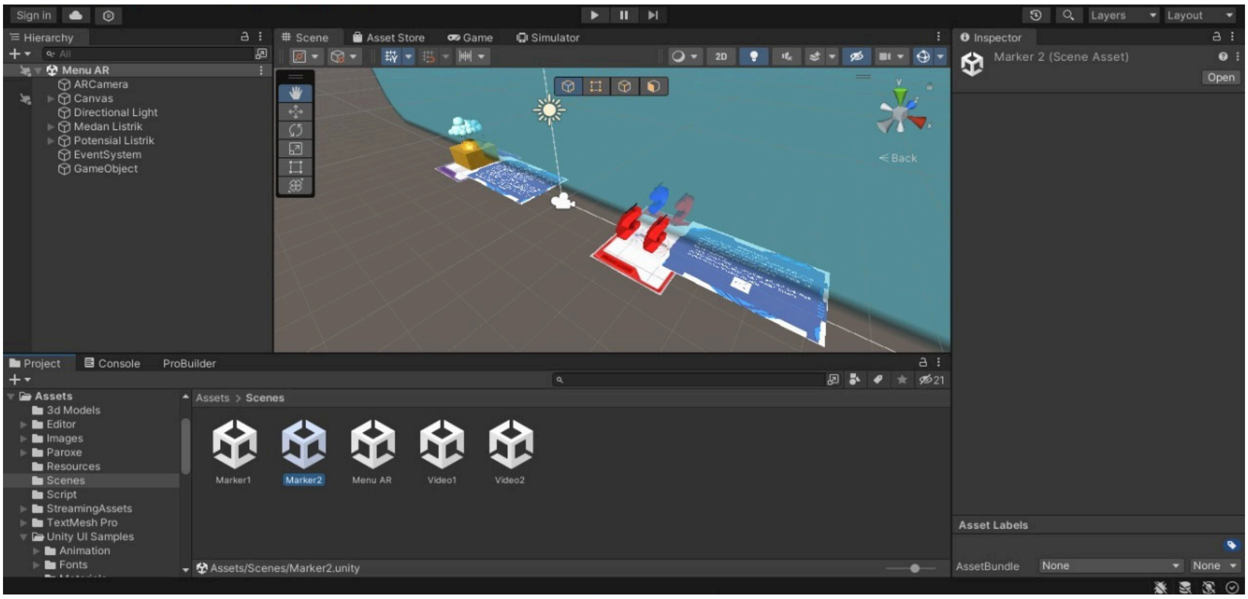

Figure 6. AR animation design with Unity 3d

Figure 6 illustrates the gamification-augmented reality (GAR) design within the unity application, explicitly targeting the introductory electrical and electronics engineering course. The creation process of GAR in Unity encompassed multiple phases, integrating gamification with augmented reality. A critical aspect of developing this AR educational application was ensuring animated objects are visible solely upon activation by the smartphone camera's recognition of the tag image.

For the creation of 3D objects, it is advised to employ external applications like 3DS MAX, Autodesk Maya, and Blender alongside Unity. Unity's primary function is to facilitate the presentation of pre-existing 3D models on marker through animations, sounds, and interactive elements.

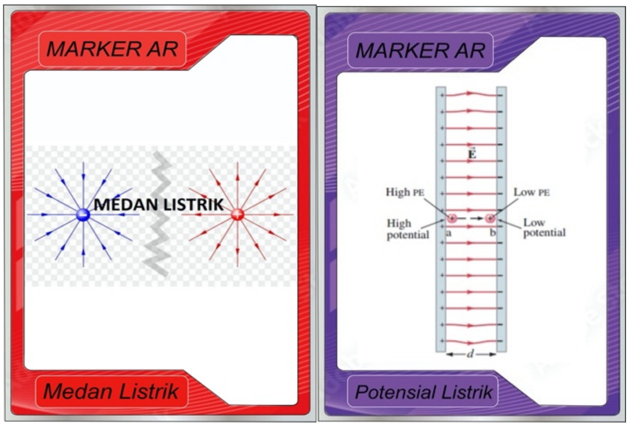

Figure 7. AR marker designing

A critical requirement for developing an AR marker-based tracking application is a marker with an image pattern for detecting and displaying pre-configured 3D objects in Unity. Unity registers this pattern in the Vuforia SDK database and manages the animation interactions of the visualized objects through the marker.

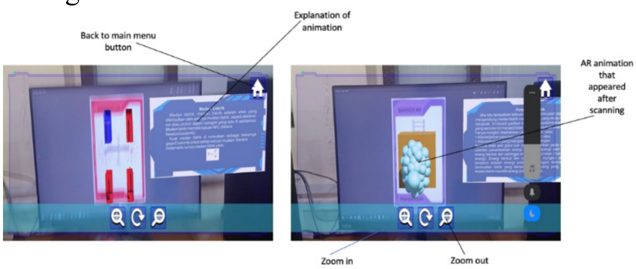

Figure 8. AR visualization of electrical engineering

In Unity, triggering the card's animation model with a smartphone camera necessitates further assets and animations for enhanced interactivity, as illustrated in Figure 8. This research utilized electrical components for AR animations, enriching the learning and comprehension of electrical engineering concepts. AR animation facilitates the visualization of these concepts, enabling students to grasp the principles of electrical circuits and phenomena through dynamic visual representations of mathematical theories or abstractions.

Expert Validation: Before integration into learning activities, this GAR requires validation testing to achieve a valid status.

Validation data is collected from instrument evaluations by media, computer, and animation experts. The input from validators serves as feedback for revisions until the GAR is deemed valid and suitable for learning.

Table 6. Expert validation results of the GAR

Aspects	Indicators	Mean			Aiken's V Coefficient	Category
		V1	V2	V3		
Construction Term	This GAR media systematically presents its content.	4.7	4.8	5.0	0.72	Valid
	GAR user interface is simple, clear, and easy-to-understand sentences.	4.0	4.9	4.8	0.71	Valid
Technical Term	GAR is user-friendly, stand-alone, self-instructional, self-contained, and adaptive	4.9	5.0	4.8	0.86	Valid
	It showcases clear and appealing animations related to GAR	4.8	4.9	5.0	0.83	Valid
	Including text and animation enhances the comprehensibility of the instructional content for students.	4.9	4.9	4.4	0.78	Valid
	This GAR interface is attractive.	5.0	4.7	5.0	0.81	Valid

Table 6 displays the expert validation results for GAR. The validation confirms GAR's validity in construction and technical aspects, with all five indicators having an average Aiken's V coefficient above 0.6. Each indicator, such as systematic material presentation (V=0.72) and engaging animations (V=0.86), contributed to the overall validation. Experts found GAR valid, supporting its application in learning and enabling the analysis of its effectiveness.

Trials: Following expert validation, the trial stage demonstrates that an integrated problem-case method with GAR enhances classroom interactivity and students' critical and creative thinking skills in learning activities. This aligns with previous research [47], suggesting that integrating the problem-case method with GAR enhances student skills [49]. Additionally, it emphasizes improving creativity and critical thinking skills through real cases in problem-based learning.

Table 7. Percentage of interactivity in the classroom in the treated group

Item	Very Often	Often	Rare	Never	M	SD
Students may use tutorial software	18 (60%)	7 (23.3%)	5 (16.7%)	0 (0%)	25.8	32.0
Students' use of ICT shifts from a reactive to a constructive style.	17 (56.7%)	5 (16.7%)	5 (16.7%)	3 (10%)	24.0	29.7
The student has significant influence over the activity direction within the constraints of the provided software and their proficiency in using it.	20 (66.7%)	5 (16.7%)	5 (16.7%)	0 (0%)	26.3	36.4
Students participate in independent and reflective activities in a collective whole-class setting, collaboratively organizing elements. They select ICT tools to structure their thoughts, guided by the teacher and fellow students.	22 (73.3%)	6 (20%)	2 (6.7%)	0 (0%)	27.5	41.1

Data analysis on the impact of the GAR-integrated problem-case method on classroom interactivity reveals that the percentage of "very often" was highest across all indicators (Table 7). The indicator "Independent, reflective activity carried out collectively by students in a whole-class context, with the teacher and students arranging factors such as the selection of ICT tools to help structure thought" had the highest mean of 27.5 (SD = 41.2), with 73.3% of students highly adaptable in the whole-class context. However, the lowest mean among the indicators was "Students' use of ICT shifts from a reactive to a constructive style," at 24 (SD = 62.6), indicating that 56.7% of students often use software.

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Table 8. T-Test analysis of interactivity classroom

Observations	Groups	N	Paired Sample T-test			
			Mean	t	df	P
Pretest-posttest analysis of interactivity classroom instrument	Experimental Group	30	3.63	7.936	29	0.000
	Control Group	30	7.83	0.976	29	0.551
			Independent Sample T-test			
			M	t	df	P
Post-test comparison analysis of interactivity classroom instrument	Experimental Group	30	73.27	7.738	58	0.000
	Control Group	30	50.42			

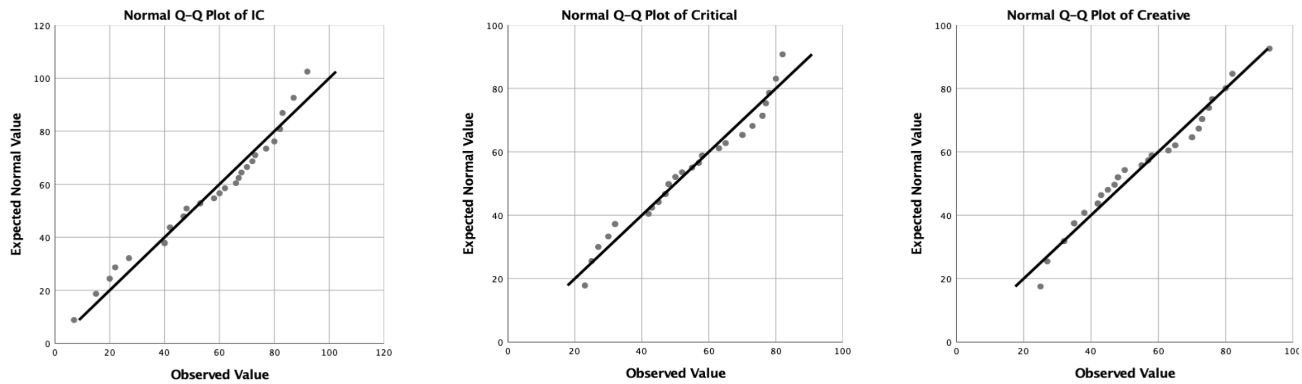
Table 8 indicates a significant difference in Classroom Interactivity between the experimental and control groups (df=58, t=7.738, p-value=0.00, p<0.05). The post-test revealed that the experimental group surpassed the control group in classroom interactivity.

The treatment's impact is evident in the post-test scores, demonstrating improvement after applying the problem-case method integrated with GAR. A p-value below 0.05 led to rejecting the null hypothesis (H0), signifying a difference in post-test scores between the experimental and control groups.

Table 9. Interactivity analysis framework

Aspects	Student - Teacher interaction	Individual interaction	Group interaction	Interaction with GAR
Authoritative interactivity	Digesting the case given by the teacher	Watching	Constructing	Following standard procedures
Dialectic interactivity	Investigate the case given by the teacher	Exploration talking	Doing, Exploring	Search for information by reading materials
Dialogic interactivity	Collect alternative solutions	Brainstorming talking	Creating, Doing	
Synergistic interactivity	Provide solutions to the given case	Solution and contribution talking	Talking, Using, Doing	Elaborate problem-solving/case material

In conclusion, GAR influenced classroom interactivity, aligning with Anjos, F. E. et al.'s research [50], emphasizing augmented reality's direct interaction with learning content. Augmented reality enables viewing 3D objects, running simulations, and participating in location-based activities, fostering an interactive and immersive learning experience. Engaging students through interactive experiences and gamification elements enhances information retention, as hands-on and interactive activities are more memorable [51]. Detailed interactions from the study are presented in Table 9.



(a) (b) (c)

Figure 9. Plot QQ normality test of interactivity classroom (a), Critical thinking skill (b), and Creative thinking skill (c)

Figure 9 usually depicts distributed research data. Shapiro-Wilk tests for classroom interactivity (Figure 7a) [p > 0.05, W = 0.85], critical thinking skills (Figure 7b) [p > 0.05, W = 0.83], and creative thinking skills (Figure 9b) [p > 0.05, W = 0.72] confirm normal distribution. QQ Plot illustrations for each variable display scattered points forming a line pattern, satisfying the normality assumption.

Thus, the research data is suitable for parametric analysis (Table 8, Table 11, and Table 12) as it meets the analysis requirements.

Table 10. Percentage of students' critical and creative thinking skills in treated group

Item	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	M	SD
Critical Thinking Skill							
Explanation of issues	18 (60%)	10 (33.3%)	2 (6.7%)	0 (0%)	0 (0%)	27.2	38.8
Evidence (The utilization of information to examine a particular perspective or conclude)	17 (56.7%)	7 (23.3%)	3 (10%)	3 (10%)	0 (0%)	25.6	34.8
The study examines the impact of context and underlying assumptions.	18 (60%)	8 (26.7%)	3 (10%)	1 (3.3%)	0 (0%)	26.6	37.7
Student's position (hypothesis/ thesis, perspective).	19 (63.3%)	9 (30%)	1 (3.3%)	1 (3.3%)	0 (0%)	27.2	40.7
Creative Thinking Skill							
Generate novel and valuable ideas	19 (63.3%)	10 (33.3%)	1 (3.3%)	0 (0%)	0 (0%)	27.6	41.3
Elaborate, refine, analyze, and assess their ideas to enhance and optimize creative endeavors.	18 (60%)	8 (26.7%)	3 (10%)	1 (3.3%)	0 (0%)	26.6	37.7
Formulate, develop, execute, and proficiently convey new ideas to others	23 (76.7%)	5 (16.7%)	1 (3.3%)	1 (3.3%)	0 (0%)	28	49.3
Demonstrate receptivity to varied perspectives and be responsive to new ideas; integrate group input and feedback into the collaborative effort.	17 (56,7%)	9 (30%)	3 (10%)	1 (3.3%)	0 (0%)	26.4	35.8

Data analysis for the problem-case method combined with GAR revealed the highest percentage of "strongly agree" in all critical thinking skills indicators (Table 10). The indicator "Student's position (perspective, thesis/hypothesis)" scored the highest mean of 27.2 (SD=40.7), with 63.3% expressing their perspective and hypothesis effectively. The lowest mean was "Evidence (Selecting and using the information to investigate a point of view or conclusion)," at 25.6 (SD = 34.3), indicating 56.7% effectively selecting and investigating information. Similarly, the impact of the problem-case method integrated with GAR on students' creative thinking skills revealed the highest percentage of "strongly agree" in all indicators (Table 10). The indicator "Develop, implement and communicate new ideas to others effectively" scored the highest mean of 28 (SD=49.3), with 76.7% effectively developing and expanding their ideas. The lowest mean was "Be open and responsive to new and diverse perspectives; incorporate group input and feedback into the work," at 26.4 (SD = 35.8), indicating 56.7% were responsive to new perspectives and contributed input in case/problem-solving.

Table 11. T-Test analysis of critical and creative thinking skills

Observations	Groups	N	Paired Sample T-test			
			Mean	**t**	**df**	**P**
Pretest-Posttest analysis of critical thinking skill instrument	Experimental Group	30	2.86	7.773	29	0.000
	Control Group	30	6.98	0.683	29	0.873
			Independent Sample T-test			
Post-test comparison analysis of critical thinking skill instrument			**M**	**t**	**df**	**P**
	Experimental Group	30	76.82	7.643	58	0.000
	Control Group	30	46.86			
			Paired Sample T-test			
			Mean	**t**	**df**	**P**
Pretest-Posttest analysis of creative thinking skill instrument	Experimental Group	30	4.86	9.438	29	0.001
	Control Group	30	8.52	0.835	29	0.546
			Independent Sample T-test			
			M	**t**	**df**	**P**
Post-test comparison analysis of creative thinking skill instrument	Experimental Group	30	77.63	8.538	58	0.000
	Control Group	30	48.15			

Table 11 indicates a significant difference in students' creative thinking skills (df=58, t=8.538, p-value=0.00, p<0.05) and critical thinking skills (df=58, t=7.643, p-value=0.00, p<0.05) between the experimental and control groups. The experimental group demonstrated superior critical and creative thinking skills in the post-test compared to the control group, showcasing the impact of the treatment when applying the problem-case method integrated with GAR. The rejection of the null hypothesis (H0) implies a difference in post-test scores between the experimental and control groups.

Implementing gamification-augmented reality (gar) in learning positively influences students' creative and critical thinking skills. This concurs with the findings of H. Hedberg et al. [52], asserting that AR enables students to explore and discover new concepts, fostering curiosity, creativity, and critical thinking. Gamification-augmented reality provides a practical context for creativity, empowering students to design AR solutions for real-world issues and apply their creative and critical thinking skills in authentic situations [53].

Table 12. ANCOVA analysis

Source	Df	Mean square	F	p	η2
Pre-test	1	154.615	18.863	0.000	0.187
Group	1	1776.429	19.825	0.000	0.172
Error	57	85.586			
Total	60				

Table 12 reveals a statistically significant difference in classroom interactivity and students' critical and creative thinking skills between the experimental and control groups ($F(1,57) = 19.825$, $p < 0.05$, $\eta^2 = 0.172$). The effect size (η^2) of 0.172 denotes a substantial impact, suggesting that the gamification-augmented reality-integrated case technique was more effective than traditional methods in enhancing classroom interactivity. The findings also showcased improvements in the experimental group's critical and creative thinking abilities.

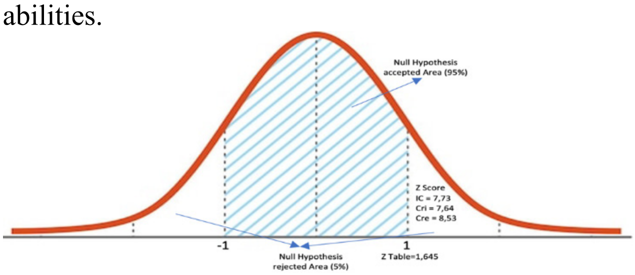


Figure 10. Trial's Z-Score Position in Normal Curve

The study's hypothesis was tested through a comparative analysis between z-count and z-table values to ascertain the null hypothesis's rejection or acceptance.

The z-count values for classroom interactivity (7.73), critical thinking skill (7.64), and creative thinking skill (8.53) exceeded the z-table value (1.645). Consequently, the null hypothesis was rejected. It can be concluded that utilizing the problem-case method integrated with GAR led to a minimum increase of 73.3% in classroom interactivity with students' critical and creative skills.

Integrating GAR in learning creates a comprehensive environment, actively engaging students and fostering the development of their creative and critical skills. Incorporating gamification-augmented reality (GAR) positively impacts classroom interactivity, creativity, and essential thinking abilities. GAR enhances classroom engagement by providing an enjoyable learning experience. Gamification elements, including points, levels, and challenges, contribute to increased student involvement. Augmented reality adds an interactive dimension, enabling students to engage directly with learning content [54].

GAR integration allows students to delve into learning content, engage in simulations, interact with 3D objects, and conduct explorations that ignite curiosity based on the study by Faridi H. et al. [37]. It fosters interactivity, stimulates creativity, and encourages critical thinking. Including 3D visualizations, animations, and AR elements enhances students' imagination, promoting the development of creative thinking through engagement in GAR-related creative activities [48]. Students can innovate, design 3D objects, and collaborate on creative projects using GAR. Moreover, GAR allows students to observe the consequences of their decisions in a realistic context, fostering a responsive learning experience. This system provides immediate feedback, stimulating critical thinking. GAR prompts students to tackle real-world problems by presenting real case-based challenges, encouraging creative solutions and critical thinking. It facilitates the connection between learning and real-world situations, fostering critical thinking [39].

During this research, it was observed that GAR enhances student motivation by making learning engaging and enjoyable. Gamification elements, like points and challenges, encourage active student participation. Augmented Reality technology in GAR creates an immersive learning experience, deepening student engagement with the material. Exposure to GAR technology improves students' digital literacy and technology skills, aligning with the demands of the contemporary workforce. The GAR system provides instant feedback, fostering adaptive learning and prompt correction.

Collaborative activities in a GAR setting contribute to developing essential soft skills such as teamwork, effective communication, and leadership, all valuable in a professional context.

The GAR system offers immediate feedback [40], enhancing engagement and aiding students in assessing and refining their decisions, thereby developing critical thinking skills. Gamification-augmented reality facilitates creative collaboration, fostering teamwork as students collaborate to attain specific objectives [46]. Collaboration provides an environment for creative thinking, problem-solving, and idea generation. Through Gamification and Augmented Reality technology, students can participate in project-based learning, implementing and showcasing their solutions [39]. Accordingly, GAR-integrated case-based learning simultaneously enhances interactivity, creativity, and critical thinking.

Gamification-augmented reality (GAR) significantly impacts classroom engagement, cognitive reasoning, and student innovation. Its implementation enhances interactivity and dynamism, fostering collaborative problem-solving and improving communication skills. This contributes to social cohesion in the classroom. In general, artificial intelligence (AI) analytical reasoning is frequently applied, enhancing critical thinking skills. Integrating gamification and augmented reality offers a dynamic learning experience, enabling students to apply creativity in solving problems. Evidence supports the positive impact of GAR on classroom engagement, establishing a foundation for enhancing students' analytical and innovative capacities in a dynamic professional landscape.

4. Conclusion and Future Work

Integrating gamification and augmented reality (GAR) enhanced the problem-case method in learning, boosting classroom interactivity and providing a more immersive learning experience. The integrated GAR application significantly supported students' creative and critical thinking, fostering flexibility in their learning roles. Augmented reality technology, offering visual context and immersive stimulation, positively influenced the development of creative and critical thinking skills. The study suggests that incorporating Augmented Reality in Problem-based learning significantly enhances students' creative and critical thinking skills, contributing valuable insights for TVET Education curriculum developers and policymakers.

While the research focused on classroom interactivity and critical and creative thinking skills, future studies could explore the impact of other variables like motivation, self-efficacy, anxiety, environment, and knowledge on creativity and critical thinking. Similar investigations in diverse learning areas and assessments of creativity components like flexibility, fluency, and originality may provide additional insights for researchers in this field.

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