Journal of Educational Technology and Learning Creativity
Vol. 3, No. 2, December 2025 pp. 367~380
ISSN: 3021-7865, DOI: 10.37251/jetlc.v3i2.2492

Integrating Realistic Mathematics Education (RME) in E-Comic Media: A Novel Approach to Foster Mathematical Creativity

Rizki Dwi Siswanto[1], Yaya S. Kusumah[2], Dadan Dasari[3], Dadang Juandi[4], Agus Hendriyanto[5], Luhur Bayuaji[6]
[1, 2, 3, 4]Department of Mathematics Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
[1]Department of Mathematics Education, Muhammadiyah University Prof. DR. HAMKA, Jakarta Selatan, Indonesia
[5]Department of Master's Program in Pedagogy, Nusa Putra University, Sukabumi, Indonesia
[6]Faculty of Data Science and Information Technology, INTI International University, Nilai, Malaysia

Article Info

Article history:

Received Aug 23, 2025
Revised Oct 27, 2025
Accepted Nov 26, 2025
Online First Dec 27, 2025

Keywords:

Educational Environment
Learning Opportunities
Mathematical Creativity
RME
Youth Empowerment

ABSTRACT

Purpose of the study: This study aims to examine the effectiveness of integrating Realistic Mathematics Education (RME) into e-comic media for junior high school students in Jakarta in order to foster mathematical creativity and improve students' ability to connect mathematical concepts with real-life situations.

Methodology: This study employed a Research and Development (R&D) design using the ADDIE instructional model to develop RME-based e-comic media. The product was implemented with junior high school students in Jakarta, and data on mathematical creativity and learning responses were collected using creativity tests, questionnaires, classroom observations, and analyzed using descriptive and inferential statistics.

Main Findings: The results indicate that RME-based e-comic media significantly improved students' mathematical creativity across all indicators, including fluency, flexibility, originality, elaboration, and insight. Students showed higher learning motivation, more active engagement in discussions, and an increased ability to relate mathematical concepts to daily life, while teachers reported more dynamic classroom interactions, participation, and collaboration.

Novelty/Originality of this study: This study introduces an innovative integration of Realistic Mathematics Education with interactive e-comic media to foster mathematical creativity in junior high school students. It advances mathematics education by demonstrating how context-rich, visually engaging digital narratives can transform conventional instruction into student-centered, creativity-oriented learning experiences and provides a scalable model for technology-enhanced, creativity-focused mathematics instruction.

Corresponding Author:
Yaya S. Kusumah,
Department of Mathematics Education, Universitas Pendidikan Indonesia,
Jl. Dr. Setiabudhi No. 229 Bandung 40154 West Java, Indonesia
Email: yskusumah@upi.edu

1. INTRODUCTION

Mathematics education is one of the main pillars in curriculum development worldwide due to its crucial role in shaping students' critical and creative thinking skills [1]-[4]. However, a 2022 report shows that Indonesia still ranks low in mathematical ability, with an average score of 379, far below the OECD average of 489 [5], [6]. This data indicates the need for reform in mathematics teaching approaches that not only focus on conceptual

understanding [7] but also on practical application in daily life [8]-[10]. One promising approach to address this challenge is Realistic Mathematics Education (RME), which emphasizes the importance of contextual relevance in mathematics learning [11]-[13]. By making mathematics more meaningful and applicable [14], RME aims to help students develop both mathematical creativity and problem-solving skills [15]-[17].

RME, a pedagogical approach developed in the Netherlands [18], highlights the importance of context in mathematics learning [19], [20]. This approach encourages students to build their mathematical understanding through real-life experiences and everyday situations [21]-[23]. RME invites students to engage in active learning processes, where they can develop problem-solving strategies relevant to the contexts they face [19], [24]. In RME, students do not only learn mathematical concepts theoretically but also apply them in practical situations, such as budgeting, measurement, or data analysis [11], [25], [26]. In this way, RME helps students develop the critical and creative thinking skills that are highly needed in real life [27], [28]. Research shows that students who learn mathematics through the RME approach have a better understanding and are more capable of applying mathematical concepts in real situations [19].

Mathematics not only plays a role in the development of cognitive abilities but also has a significant impact on students' social development [29]-[31]. According to Harahap et al. [32], strong mathematical proficiency enables students to solve problems, think critically, and make sound decisions. In today's digital era, mathematical skills are also key to participating in an increasingly complex and technology-based society [33]-[35]. In fact, Yi and Park [36] report places mathematical and analytical skills as one of the four main competencies needed in the future job market.

Mathematical creativity is one important aspect of mathematics learning that is often overlooked. This creativity includes students' ability to generate new ideas, find various ways to solve problems, and connect mathematical concepts to real-life situations [37]-[40]. According to Leikin [41], mathematical creativity is not only important for enhancing students' understanding of mathematical concepts but also for preparing them to face real-world challenges that require innovative thinking. In the educational context, mathematical creativity can be developed through learning approaches that encourage exploration, problem-solving, and the application of concepts in various situations.

However, a major challenge in mathematics education is how to make learning more engaging and relevant for students [42]-[44]. Many students perceive mathematics as a difficult and boring subject, which ultimately reduces their motivation and engagement in the learning process [45]-[47]. Therefore, innovative and engaging approaches are needed to overcome these negative perceptions. One potential solution is to combine RME principles with digital media, such as e-comics. E-comic media can present mathematical concepts visually and interactively , while also providing real-life contexts relevant to students' lives. With this approach, it is expected that students will better understand mathematical concepts, see their relevance in daily life, and develop their creativity in problem-solving [48]-[50].

In this context, the integration of digital media such as e-comics offers a new and effective way to deliver mathematical concepts in an engaging and interactive manner [51]-[54]. E-comics not only attract students' attention but also provide relevant contexts and real-life situations that make it easier for students to understand and apply mathematical concept [34], [55], [56]. Through e-comics, students can see the connection between mathematics and everyday life, thereby increasing their motivation and creativity in learning [34], [57], [58].

E-comics as learning media offer an innovative way to deliver information and concepts [59]-[62]. In the educational context, e-comics can be used to explain mathematical concepts visually and attractively [63], [64], [65]. Research by Berger et al. [59] shows that the use of e-comics in learning can increase students' motivation and help them understand the material better. E-comics also allow students to learn independently and flexibly, which is very important in modern education [63]-[66]. One of the advantages of e-comics is their ability to present interesting and relevant stories, which can help students relate mathematical concepts to their life experiences [67]. For example, e-comics depicting certain social or cultural situations can help students understand the application of mathematics in a broader context. In addition, interactive elements in e-comics allow students to be more actively involved in the learning process [34], [57], [58], [68], thereby improving their understanding and retention of the material taught.

This study aims to explore how the integration of RME in e-comic media can enhance students' mathematical creativity. It also seeks to provide insights into the effectiveness of this approach in the context of mathematics education in Indonesia. By understanding how e-comics can be used as effective learning tools, this research is expected to offer recommendations that can be applied in educational practice. The significance of this research lies in its contribution to the development of more innovative and relevant mathematics teaching methods. By combining RME and e-comics, it is expected that students will not only better understand mathematical concepts but also develop the creative thinking skills that are highly needed in a constantly changing world. Furthermore, this research is also expected to serve as a foundation for further studies in mathematics education and the use of technology in learning.

Several previous studies have highlighted the effectiveness of RME in improving students' understanding of mathematical concepts. For example, research by Van den Heuvel-Panhuizen and Drijvers [69] shows that RME

helps students relate mathematical concepts to real contexts, thereby enhancing their understanding. However, these studies have not specifically explored the use of digital media such as e-comics in the implementation of RME. Research by Diah et al. [70] shows that the use of comic media in education can increase students' motivation and interest in learning materials. However, this research focuses more on the visual and narrative aspects of comics without considering the integration of RME principles. This indicates a gap in understanding how e-comics can be effectively used to support realistic mathematics learning.

Leikin [41] emphasizes the importance of creativity in mathematics learning but does not link this creativity to the use of e-comics in the context of RME. This research shows a relationship between creativity and problem-solving but does not explain how e-comics can contribute to the development of mathematical creativity. Thus, there is a clear research gap in integrating RME with e-comic media. Although both have the potential to enhance mathematics learning, no study has comprehensively examined how e-comics can be used to apply RME principles in mathematics learning.

Another gap is the lack of focus on the impact of using e-comics in enhancing mathematical creativity. Existing studies have not sufficiently explored how the narrative and visual elements in e-comics can stimulate students' creativity in solving mathematical problems. Further research can explore this relationship using more structured methodologies, such as experiments or case studies. In addition, many previous studies tend to focus on a single context or specific population, such as elementary or secondary school students. There is a need for research in more diverse contexts, including students from different backgrounds and cultural settings. This research can provide broader insights into the effectiveness of integrating RME and e-comics in improving mathematics learning in various settings.

Previous studies have also not sufficiently delved into the design and development of e-comics that align with RME principles. There is a need for research focusing on design aspects, including how visual and interactive elements can be integrated to support realistic learning. This research may include the development of e-comic prototypes that are then tested in learning contexts. Finally, there is a gap in evaluating the effectiveness of using e-comics in the context of RME. Previous studies often do not provide clear measurement tools to assess the impact of e-comic use on students' mathematical understanding and creativity. Further research can develop evaluation instruments that can be used to measure student learning outcomes more accurately. By addressing these gaps, this study is expected to provide a better understanding of the potential use of e-comics in supporting realistic and creative mathematics learning.

2. RESEARCH METHOD

This project is a Research and Development (R&D) study utilizing the ADDIE development model (Analysis, Design, Development, Implementation, Evaluation). The ADDIE model was chosen because it provides a systematic framework for developing e-comic-based learning media integrated with the Realistic Mathematics Education (RME) approach. The aim of this research is to produce innovative learning media that can enhance students' mathematical creativity. Testing was conducted using both quantitative and qualitative approaches to evaluate the effectiveness of the developed media.

2.1. Research Stages

The research stages follow the ADDIE model, which consists of five main steps: Analysis, Design, Development, Implementation, and Evaluation. Each stage is described as follows:

Table 1. R&D Project Implementation Stages with the ADDIE Model

Stage	Activity Description	Outcomes
Analysis	- Conducting needs analysis through interviews and questionnaires with teachers and students to understand students' difficulties in learning mathematics. - Analyzing the curriculum to ensure material alignment with learning objectives. - Literature review related to RME, mathematical creativity, and e-comic media.	Identification of learning needs, relevant materials, and the potential for integrating RME into e-comic media.
Design	- Designing RME-based e-comic content, including storyline, visuals, and interactive elements. - Developing contextual problems aligned with RME principles, such as phenomenological exploration and students' own contribution. - Preparing evaluation instruments, such as mathematical creativity tests and student satisfaction questionnaires.	Initial design of RME-based e-comic media and evaluation instruments ready for further development.
Development	- Developing an RME-based e-comic prototype based on the designed plan. - Validation by media experts, mathematics content experts, and education experts. - Revising based on expert feedback to improve media quality.	Validated and revised RME-based e-comic media prototype.

Stage	Activity Description	Outcomes
Implement ation	- Conducting limited trials with small groups of students to identify technical and pedagogical issues. - Field testing with larger student groups to evaluate media effectiveness. - Collecting data through mathematical creativity tests, student satisfaction questionnaires, and interviews.	Data from limited and field trials to evaluate the effectiveness of the RME-based e-comic media.
Evaluation	- Conducting formative evaluation at each ADDIE stage to ensure the media aligns with learning objectives. - Conducting summative evaluation after implementation to assess the media's effectiveness in enhancing students' mathematical creativity.	Effective RME-based e-comic media and recommendations for further development.

2.2. Testing Approach

This study uses both quantitative and qualitative approaches to evaluate the effectiveness of the RME-based e-comic media.

Table 2. Evaluation Design for the Effectiveness of RME-Based E-Comic Media

Approach	Purpose	Instruments	Data Analysis
Quantitative	The quantitative approach is used to measure the effectiveness of the media in enhancing students' mathematical creativity.	1. Mathematical Creativity Test: Measures aspects of fluency, flexibility, originality, and elaboration in solving mathematical problems. 2. Student Satisfaction Questionnaire: Measures students' satisfaction with the developed e-comic media.	Quantitative data are analyzed using descriptive and inferential statistics to observe differences in learning outcomes before and after using the media.
Qualitative	The qualitative approach is used to explore students' and teachers' experiences in using the RME-based e-comic media.	1. Interviews: Conducted with students and teachers to obtain feedback on the strengths, weaknesses, and impact of the media on learning. 2. Observation: Observing the learning process to see how students interact with the media and how the media facilitates RME principles.	Interview and observation data are analyzed thematically to identify students' and teachers' experiences in using the RME-based e-comic media.

2.3. Research Subjects

The research subjects consisted of students from a junior high school in Jakarta, selected using cluster random sampling for the quantitative approach and purposive sampling for the qualitative approach. The experimental group used the RME-based e-comic media, while the control group used conventional teaching methods. Mathematics teachers were also involved to provide input regarding the implementation of the media.

2.4. Development of E-Comic Media

The development of RME-based e-comic media aims to create innovative learning tools that can enhance students' mathematical creativity. This development process was carried out systematically, referring to the conceptual framework, design process, and initial testing to ensure the resulting media is relevant, effective, and meets learning needs.

2.5. Conceptual Framework for E-Comic Development

The conceptual framework for developing RME-based e-comics is designed to support meaningful mathematics learning and enhance students' mathematical creativity. Mathematical creativity, defined as the ability to generate new ideas, solve problems innovatively, and connect mathematical concepts in various contexts, is the main focus in developing this media. By integrating RME principles, the e-comic is designed to create a learning environment that encourages exploration, reflection, and knowledge construction [71] by students.

RME principles, as described by Treffers [72] and Van den Heuvel-Panhuizen and Drijvers [69], provide the foundation for developing e-comics that are not only visually appealing but also effective in facilitating creative learning. The relationship between RME principles and the development of mathematical creativity is as follows:

1. Phenomenological Exploration: Contextual problems relevant to students' daily lives serve as the starting point for learning. These problems are designed to trigger exploration and encourage students to think creatively in finding solutions. Mathematical creativity emerges when students can connect their real-life experiences with mathematical concepts.

2. Bridging by Vertical Instruments: Visual models and representations in the e-comic help students bridge understanding from concrete to abstract situations. This process enables students to develop creative solutions using tools or models they create themselves, such as diagrams or symbols.
3. Students' Own Contribution and Production: In RME, students are encouraged to produce their own solutions through exploration and reflection. This aligns with the development of mathematical creativity, where students are given the freedom to try various approaches and strategies in problem-solving.
4. Interactivity: Interaction among students, both individually and in groups, encourages discussion and collaboration. This process allows students to share ideas, learn from others' perspectives, and develop more creative solutions.
5. Intertwinement: The e-comic integrates various mathematical concepts simultaneously, such as geometry, algebra, and arithmetic. This provides students with opportunities to see relationships between concepts and apply them in various situations, which is at the core of mathematical creativity.

Meanwhile, mathematical creativity in RME-based e-comics is facilitated through story design and activities intended to encourage students to think beyond existing patterns or procedures. Some key elements supporting the development of mathematical creativity include:

1. Open-Ended Problems: The stories in the e-comic present open-ended problems with more than one solution. This encourages students to think creatively and explore various approaches to problem-solving.
2. Flexibility in Problem Solving: Students are given the freedom to use their own strategies in solving problems. This process allows students to develop flexible thinking, which is one of the main indicators of mathematical creativity.
3. Reflection and Discussion: The e-comic is designed to facilitate reflection and discussion, both individually and in groups. Students are encouraged to reflect on their thinking processes, compare solutions with their peers, and learn from different perspectives.

2.6. Design Process

The design process of the RME-based e-comic involves several key steps, from creating the storyline to integrating RME principles into the content. This process is designed to produce media that is relevant, engaging, and aligned with students' learning needs.

2.6.1. Storyboarding and Content Creation

The first step in the design is creating the storyboard and content. The storyboard is used to design the e-comic's storyline, including dialogue, illustrations, and other visual elements. This process involves:

1. Identifying Contextual Problems: Each story begins with a contextual problem relevant to students' lives, such as everyday situations involving measurement, calculation, or patterns.
2. Developing Characters and Narratives: Characters in the e-comic are designed to attract students' attention and motivate them to engage with the story. The narrative is structured to guide students through exploration and problem-solving processes.
3. Visualizing Mathematical Concepts: Illustrations are used to visualize mathematical concepts, such as graphs, diagrams, or models, so that students can understand the relationship between concrete and abstract concepts.

2.6.2. Pilot Testing and Feedback

After the design process is complete, the e-comic is validated by evaluators and then tested on a small group of students to evaluate its effectiveness. This stage involves collecting feedback from students and teachers to improve the media before large-scale implementation.

2.6.3. Initial Testing with Target Audience

Initial testing is conducted on a small group of students who are the target users of the e-comic. Activities include:

1. Using the E-Comic in Learning: Students use the e-comic in mathematics learning to solve contextual problems presented in the story.
2. Data Collection: Data is collected through observation, interviews, and questionnaires to evaluate students' experiences in using the e-comic. The main focus is on aspects of engagement, understanding, and creativity.

The results of the initial testing provide insights into the strengths and weaknesses of the media, such as whether the story is engaging, whether the illustrations aid understanding, and whether the contextual problems are relevant to students' experiences.

2.6.4. Revisions Based on Feedback

Based on feedback from evaluators and initial testing, revisions are made to improve the quality of the e-comic. Some aspects improved include:

1. Refining the Storyline: The story is adjusted to be more relevant to students' experiences and more effective in triggering mathematical exploration.
2. Enhancing Visualization: Illustrations and visual models are improved to ensure they support students' understanding of mathematical concepts.
3. Adjusting Contextual Problems: Problems that are less relevant or too difficult are adjusted to match students' ability levels.

These revisions aim to ensure that the resulting e-comic is not only visually appealing but also effective in supporting RME-based learning and enhancing students' mathematical creativity.

2.6.5. Implementation of E-Comic Media in RME for the Development of Mathematical Creativity

The integration of RME into e-comic media offers an innovative approach to fostering students' mathematical creativity. Through e-comics, mathematical concepts are not only presented abstractly but also linked to real-life contexts that are relevant and easily understood by students. This approach aligns with the main principle of RME, which is to start mathematics learning from situations that are meaningful and close to students' everyday experiences.

The use of e-comics as learning media enables the presentation of stories, visualizations, and interactive dialogues that can spark curiosity and encourage students to think creatively in solving mathematical problems. Illustrations in the e-comic are designed to depict the mathematical thinking process, from identifying problems, exploring various solution strategies, to reflecting on the solutions found. Thus, students not only learn mathematical concepts but also develop divergent thinking, originality, and flexibility in finding solutions.

The following section presents an example illustration of the integration of RME and the development of mathematical creativity in e-comic media. Table 3 provides details of the learning stages, activities conducted, and aspects of mathematical creativity developed through each stage.

Table 3. Sample Illustration of RME Integration and Mathematical Creativity Development in E-Comic Media

Panel	Visual Description	Dialogue/Narration	Interactive Notes
Panel 1: Opening (Phenomenological Exploration)	A lively classroom, the teacher brings gift boxes of various shapes (rectangular prism, cylinder, triangular prism). Students look curious.	Teacher: "Class, the school will hold a gift box design competition! You have to decorate and wrap boxes with unique shapes. But, how much wrapping paper is needed for each box?" Student A: "Wow, that's exciting! But how do we calculate it, Ma'am?" Teacher: "That's the challenge! You can use any method. Go ahead and explore!"	"Let's Explore!" panel
Panel 2: Problem Exploration (Bridging by Vertical Instruments)	Students open the boxes, draw nets on paper, some measure sides with rulers, others use apps on their phones.	Student B: "I'll open the box and draw its net on paper. I'll measure each part with a ruler." Student C: "I'll try calculating the area of each side and then add them up." Student D: "I'll use an app on my phone to draw the shape."	"Try Different Ways!" panel
Panel 3: Discussion and Comparison (Students' Own Contribution and Production)	Students discuss in groups, compare results, some write on the board.	Student A: "Mine is 120 cm^2. How about yours?" Student B: "I got 118 cm^2 because I forgot to count the bottom." Student C: "I prefer using nets; it's easier to see which parts have been counted." Teacher: "Great! Each method has its strengths and challenges. Discuss which is most efficient."	"Discuss Your Strategy!" panel
Panel 4: Interactivity	Students ask each other, some write on the board, teacher facilitates discussion.	Student D: "How do we calculate the surface area if it's a cylinder?" Student E: "Maybe we can open the cylinder into a rectangle and two circles?" Teacher: "Who else has ideas? Please present them to the class!"	"Let's Present!" panel

Panel	Visual Description	Dialogue/Narration	Interactive Notes
Panel 5: Intertwinement	Students connect geometry, arithmetic, and algebra concepts. There's a comparison table of formulas on the board.	Student F: "For a rectangular prism, the surface area is $2(l \times w + l \times h + w \times h)$. For a cylinder, there are circles and a rectangle." Student G: "So, we can use formulas, but also nets. They're interconnected!"	"Find the Connections!" panel
Panel 6: Open-Ended Problem & Production	Students design their own gift boxes, some make star shapes, triangles, etc.	Teacher: "Now, create your own unique gift box design! Calculate its surface area, then present it to your friends." Student H: "I want to make a triangular prism box!" Student I: "I'll try a cylinder with a half-sphere lid!"	"Create Your Own!" panel
Panel 7: Reflection and Discussion	Students write in notebooks, discuss in small groups.	Teacher: "Which strategy did you like best? What challenges did you face? How was your friend's solution different from yours?" Student J: "I learned there are many ways to calculate surface area. I like group discussions because I can learn from friends."	"Reflect on Your Experience!" panel
Panel 8: Closing	Students present their designs and calculations to the class, teacher smiles proudly.	Teacher: "You're amazing! With creativity and teamwork, you found many solutions. This is real mathematics!"	"Share Your Solution!" panel

2.6.6. Teacher Training and Support

In practice, teachers serve as the primary implementers of the products developed by researchers. This role aims to ensure that the product, in this case, the e-comic media, can be used independently by users without direct dependence on the developers. Therefore, the success of e-comic media implementation greatly depends on teachers' readiness to understand and use the media effectively in the classroom. To support this, teacher training and support are essential elements in the integration strategy. Several steps to ensure teacher readiness include:

1. E-Comic Usage Training: Teachers are trained on how to use e-comics in teaching, including how to integrate stories into classroom activities, facilitate discussions, and use visual models.
2. RME-Based Approach: Teachers are trained to understand RME principles, such as phenomenological exploration and students' own contribution, so they can apply this approach in their teaching.
3. Guidelines and Resources: Teachers are provided with guidelines and additional resources, such as e-comic-based lesson plans, to help them design appropriate classroom activities.

With adequate training and support, teachers can utilize e-comic media to create meaningful learning experiences and support the development of students' mathematical creativity.

3. RESULTS AND DISCUSSION

3.1. Student Performance Metrics

The development of e-comic learning media based on Realistic Mathematics Education (RME) began with a needs analysis involving 80 students. Sentiment analysis results showed that the majority of students perceived mathematics learning as boring, complicated, confusing, difficult, frustrating, and stressful (Figure 1).

Figure 1. Sentiment Analysis Results

These findings were further explored through in-depth interviews with selected students to gain deeper insights into their experiences and challenges in learning mathematics.

Student 1: "I often get confused when I have to solve word problems, especially when I have to find my own way. Sometimes I don't know where to start."
Student 2: "Learning is just from books and the blackboard, so I get bored quickly. Sometimes I lose interest in paying attention."
Student 3: "I don't know what mathematics is useful for in daily life. So sometimes I feel that learning math is difficult and unimportant."

These interviews not only confirmed the survey results but also provided a concrete picture of the obstacles students face, both in terms of conceptual understanding, learning motivation, and the relevance of the material to everyday life. The direct quotes from students clearly show that the problems are complex and interconnected, highlighting the need for innovation in learning media to address them.

Based on the needs analysis and in-depth interviews, it can be concluded that the main challenges in mathematics learning lie in low motivation, lack of media variety, and students' difficulties in understanding and relating mathematical concepts to real life. These issues underscore the importance of innovation in material presentation to make learning more engaging, relevant, and capable of fostering student creativity. Therefore, the development and implementation of RME-based e-comic media was chosen as a solution expected to address these needs and have a positive impact on the process and outcomes of mathematics learning.

The implementation of RME-based e-comic media was carried out in two groups: the experimental group (using e-comics) and the control group (using conventional methods). To measure the impact of the intervention, pretests and posttests were conducted in both groups. N-Gain analysis was used to assess the improvement in students' mathematical creativity. In the experimental group, the overall average N-Gain reached 85.4, which falls into the highly effective category. In detail, the N-Gain for each creativity indicator was as follows: Fluency (83.8), Flexibility (85.4), Originality (86.3), Elaboration (83.3), and Insight (87.2). This indicates that e-comics are highly effective in encouraging students to gain new insights, generate original ideas, and try various approaches in solving mathematical problems.

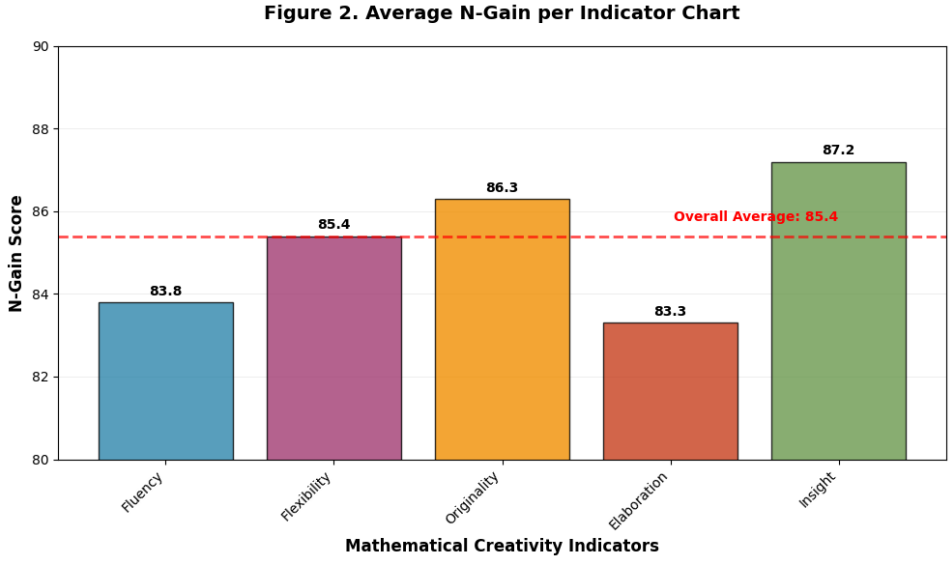

Figure 2. Average N-Gain per Indicator Chart

The relatively lower increase in the Elaboration indicator suggests that the aspect of idea development still requires more attention in the learning process. However, overall, all indicators showed very good improvement, indicating that RME-based e-comics can comprehensively foster students' mathematical creativity.

3.2. Comparison with Traditional Methods

A systematic comparison of effectiveness was conducted between the experimental group using RME-based e-comic media and the control group using traditional teaching methods to ensure the validity of the research results. The first step was to conduct an initial equivalence test through normality, homogeneity, and independent t-tests on the pretest data. The normality test results showed significance values of 0.194 for the experimental group and 0.121 for the control group, both greater than 0.05, indicating that the data were normally distributed.

The homogeneity test also showed a significance value of 0.051, meaning the variances of both groups were homogeneous. Furthermore, the independent t-test on the pretest yielded a significance value of 0.685, indicating no significant difference in the mean scores between the two groups before the intervention. Thus, it can be ensured that both groups had equivalent initial abilities, making the comparison of post-intervention results more objective.

After the implementation of the learning media, posttests and the same statistical analyses were conducted. The normality test on the posttest data showed significance values of 0.2 for the experimental group and 0.068 for the control group, both still above the 0.05 threshold, indicating normal data distribution. The homogeneity test on the posttest also showed a significance value of 0.06, meaning the variances of both groups remained homogeneous. However, the independent t-test on the posttest showed a significance value of 0.00, far below 0.05, indicating a highly significant difference in mean scores between the two groups after the intervention.

Furthermore, N-Gain analysis was used to measure the effectiveness of improving mathematical creativity in both groups. The experimental group using RME-based e-comics achieved an average N-Gain of 85.4, categorized as highly effective. Meanwhile, the control group using traditional methods only achieved an N-Gain of 61, which is considered moderately effective. This difference shows that RME-based e-comic media not only significantly enhances students' mathematical creativity but also provides a more enjoyable, interactive, and relevant learning experience. Students in the experimental group showed more consistent improvement across all creativity indicators such as fluency, flexibility, originality, elaboration, and insight compared to the control group, which tended to stagnate in some aspects.

In addition, observations during the learning process also showed that students in the experimental group were more active in discussions, more willing to express ideas, and more enthusiastic in completing mathematics tasks. Conversely, students in the control group tended to be passive and less engaged both emotionally and cognitively. These findings reinforce the quantitative analysis results, indicating that the integration of RME in e-comic media can create a more conducive learning environment for developing students' mathematical creativity compared to traditional, monotonous, and less contextual teaching methods.

Therefore, it can be concluded that the use of RME-based e-comic media is significantly superior in enhancing students' mathematical creativity, both in terms of learning outcomes and the learning experience perceived by students during the process.

3.3. Qualitative Feedback from Participants

Qualitative feedback obtained from students and teachers after the implementation of RME-based e-comic media showed very significant changes in the process and atmosphere of mathematics learning. Most students stated that material presented visually and interactively through e-comics made it easier for them to understand mathematical concepts that were previously considered difficult and confusing. One student expressed, "With the pictures and stories in the e-comic, I understand the questions better and can imagine the situation. So, math doesn't feel as hard as before." Another student added, "Usually I get bored quickly when learning math, but with e-comics, I feel more excited and curious."

Furthermore, students also felt that learning became more relevant to everyday life. They could directly see how mathematical concepts are applied in various real-life situations depicted in the e-comic stories. One student said, "I just realized that math is everywhere, for example when shopping or managing time. E-comics help me understand the usefulness of math in daily life." This shows that e-comic media not only improves understanding but also fosters awareness of the importance of mathematics.

From the teachers' perspective, there were positive changes in classroom dynamics. Teachers reported that students became more active, more willing to ask questions, and more engaged in group discussions. One teacher stated, "Students who were usually passive now ask questions and discuss more often. They are also more creative in finding solutions and are not afraid to try new ways." Teachers also noted that e-comics could bridge abstract mathematical concepts with real-life contexts, making it easier for students to relate the material to their everyday experiences.

Changes in attitudes toward mathematics were also very noticeable. Students who previously considered mathematics to be boring, difficult, and irrelevant now showed much higher interest and motivation to learn. They felt more confident and were not afraid to face new challenges. One student said, "I used to be afraid of making mistakes when solving problems, but now I feel more confident because I can try different ways." Another student added, "I enjoy discussing with friends to find solutions because it turns out there are many ways to solve one problem."

Overall, these qualitative findings reinforce the quantitative results that the use of RME-based e-comic media not only enhances students' mathematical creativity and understanding but also creates a more enjoyable, interactive, and meaningful learning environment. Increased active participation, willingness to ask questions, and collaboration among students are clear indicators that this media can transform the paradigm of mathematics learning toward a more positive and constructive direction.

The results of this study clearly demonstrate that integrating Realistic Mathematics Education (RME) in e-comic media has a significant impact on improving students' mathematical creativity. These findings align with

previous studies highlighting the importance of contextual learning in mathematics education. As emphasized by Vinogradova [1] and Seabra et al. [8], the connection of mathematical concepts to real-life situations fosters creativity and problem-solving skills in students. The positive effect on students' creativity measured by fluency, flexibility, originality, and insight suggests that e-comic media, grounded in RME principles, provides an engaging and effective learning environment. Students in the experimental group exhibited notable improvements in motivation and active participation. This finding is consistent with the results of Van den Heuvel-Panhuizen and Drijvers [73], who highlighted that the use of RME promotes a more interactive and student-centered learning approach. By utilizing visual-interactive media like e-comics, the students were able to overcome the common disengagement associated with traditional methods of mathematics teaching, as discussed by Makramalla et al. [2]. Additionally, e-comics made abstract mathematical concepts more accessible and connected to real-life contexts, reinforcing the core principles of RME.

The improvement in engagement and collaboration within the experimental group strengthens the arguments presented by Hakim et al. [11] and Treffers [72], who argue that RME promotes a collaborative and reflective learning environment. In contrast, students in the control group, who followed conventional teaching methods, exhibited more passive participation, a result that aligns with previous studies emphasizing the limitations of traditional teaching methods in fostering creativity and engagement [74], [75]. This suggests that RME-based approaches are far more effective in stimulating active learning and creativity. Interestingly, while all indicators of creativity fluency, flexibility, originality, and insight showed significant improvement, the elaboration aspect still required more attention. This aligns with Silver [76], who identified that creativity in mathematics involves multiple dimensions that must be balanced for effective learning. The gap in elaboration suggests the need for further refinement in the e-comic design to include more activities that encourage students to elaborate on their problem-solving approaches, possibly through deeper exploration and critical reflection.

Moreover, the effectiveness of RME-based e-comic media in enhancing creativity was significantly higher compared to traditional methods. These findings challenge the notion that conventional methods, such as rote memorization and repetitive exercises, are sufficient for fostering creativity in mathematics. The ability of e-comics to bridge abstract concepts with real-life applications represents a major advancement in mathematics education [77]. This approach not only improves students' conceptual understanding but also fosters critical and creative thinking skills, which are essential in today's technology-driven world [78].

Qualitative feedback from students further supports these findings, as students reported that the visual and interactive nature of e-comics helped them understand mathematical concepts more clearly and made learning more enjoyable. This reflects the findings of Tesfamicael and Enge [3], who argue that learning materials that are both visually engaging and contextually relevant can significantly enhance students' understanding of mathematics. Students in the experimental group expressed higher levels of motivation, confidence, and enthusiasm, as they could see the direct application of mathematics in everyday life, an aspect that is often lacking in traditional learning methods [79]. Furthermore, teachers observed positive changes in classroom dynamics, with increased student participation and creativity. This is consistent with the research of Fajri et al. [18], which emphasizes the importance of creating a learning environment that encourages student interaction and collaborative problem-solving. Teachers also noted that e-comics helped bridge the gap between abstract mathematical concepts and concrete student experiences, facilitating a more meaningful learning process.

Despite the promising results, the study also identified some limitations, particularly in the elaboration dimension of creativity. While the students demonstrated strong improvements in fluency, flexibility, and originality, the development of more complex and refined ideas in problem-solving remains an area for future enhancement. This finding is consistent with the conclusions of Leikin and Pitta-Pantazi [41], who stress the importance of providing students with opportunities for deeper reflection and elaboration to fully develop their creative potential. Future iterations of e-comic media should consider integrating more open-ended tasks and reflective activities to further promote elaboration in mathematical problem-solving.

In conclusion, this study provides compelling evidence that integrating RME with e-comic media is an effective approach for enhancing mathematical creativity. The use of e-comics not only improves mathematical understanding but also fosters creativity, motivation, and relevance to real-world applications. This approach presents a significant step forward in overcoming the traditional barriers in mathematics education, such as low engagement and the perceived irrelevance of the material. As such, it holds great potential for transforming mathematics learning, particularly in Indonesia, by providing students with a more engaging, relevant, and creative learning experience. The success of this study underscores the importance of developing and implementing digital learning tools that align with RME principles, ensuring that students are well-prepared to face the challenges of a rapidly changing world.

4. CONCLUSION

This study demonstrates that integrating Realistic Mathematics Education (RME) into e-comic media is effective in enhancing junior high school students' mathematical creativity and their ability to connect

mathematical concepts with real-life situations. The findings indicate improvements in students' creativity, engagement, and conceptual understanding, as well as increased confidence and active participation in learning activities. The use of RME-based e-comics makes mathematics learning more contextual, meaningful, and accessible, enabling students to view mathematics as a practical and relevant tool in everyday life. These results suggest that digital and context-based learning media can play a significant role in supporting creative and meaningful mathematics learning. However, future research is recommended to involve broader educational levels and diverse cultural contexts to examine the generalizability of these findings. Further studies should also explore more varied e-comic designs, incorporate reflective learning activities, and develop more comprehensive evaluation instruments to assess the long-term impact of RME-based e-comics on students' learning outcomes and attitudes. Such efforts will strengthen the effectiveness and sustainability of this innovative approach in mathematics education.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors used ChatGPT during the preparation of this work to design graphics and images. After utilizing the tool, the authors thoroughly reviewed and edited the content as necessary and assumed full responsibility for the publication's content.

REFERENCES

[1] M. Vinogradova, "Interdisciplinary connections in teaching mathematical and environmental disciplines to students," *E3S Web Conf.*, vol. 258, 2021, doi: 10.1051/e3sconf/202125810013.

[2] M. Makramalla, A. Coles, K. le Roux, and D. Wagner, "Mathematics education for sustainable futures: A strengths-based survey of the field to invite further research action," *Educ. Stud. Math.*, vol. 119, no. 3, pp. 535–556, Jul. 2025, doi: 10.1007/s10649-025-10389-x.

[3] S. A. Tesfamicael and O. Enge, "Revitalizing sustainability in mathematics education: The case of the new Norwegian curriculum," *Educ. Sci.*, vol. 14, no. 2, p. 174, Feb. 2024, doi: 10.3390/educsci14020174.

[4] R. Masykur, I. Irwandani, A. Pricillia, and M. Aridan, "Development of science e-modules with the STEM (Science, Technology, Engineering, and Mathematics) approach for Islamic schools," *Indones. J. Sci. Math. Educ.*, vol. 7, no. 2, p. 404, Jul. 2024, doi: 10.24042/ijsme.v7i2.20835.

[5] M. R. Bilad, S. Zubaidah, and S. Prayogi, "Addressing the PISA 2022 results: A call for reinvigorating Indonesia's education system," *Int. J. Essent. Competencies Educ.*, vol. 3, no. 1, pp. 1–12, Jun. 2024, doi: 10.36312/ijece.v3i1.1935.

[6] D. Nurqamar and I. R. D. Nur, "Comparative study of Indonesian students' mathematical literacy abilities with other countries in terms of PISA-type HOTS," *Eduma Math. Educ. Learn. Teach.*, vol. 11, no. 1, p. 45, Jul. 2022, doi: 10.24235/eduma.v11i1.9924.

[7] S. Putranto and G. I. Ratnasari, "Why I am confused to apply mathematics concepts: Student perspectives on the role of mathematics in life," *Aksioma J. Progr. Stud. Pendidik. Mat.*, vol. 11, no. 1, p. 538, Mar. 2022, doi: 10.24127/ajpm.v11i1.4534.

[8] M. A. B. Seabra *et al.*, "O cotidiano como parâmetro no ensino da matemática," *Brazilian J. Dev.*, vol. 6, no. 8, pp. 56281–56294, 2020, doi: 10.34117/bjdv6n8-152.

[9] L. H. Muhaimin, D. Dasari, A. Hendriyanto, R. Andriatna, and S. Sahara, "Can augmented reality enhance students' mathematical literacy? A study on technological development for learning practice," *Int. J. Math. Educ. Sci. Technol.*, pp. 1–34, 2025, doi: 10.1080/0020739X.2025.2502398.

[10] L. H. Muhaimin, R. A. Sholikhakh, and S. Yulianti, "Unlocking the secrets of students' mathematical literacy to solve mathematical problems: A systematic literature review," *Eurasia J. Math. Sci. Technol. Educ.*, vol. 20, no. 4, pp. 1–15, 2024, doi: 10.29333/ejmste/14404.

[11] N. Hakim, A. Apriyanto, M. Mardiati, and E. Sitepu, "Implementation of the realistic mathematics education (RME) approach in geometry learning in secondary schools," *Aksioma Educ. J.*, vol. 1, no. 3, pp. 17–30, Sep. 2024, doi: 10.62872/rgn3w339.

[12] P. Pujilestari and E. Juliangkary, "Realistic mathematics education as a contextual approach in overcoming learning difficulties on circles," *JUPE J. Pendidik. Mandala*, vol. 10, no. 2, p. 569, Jun. 2025, doi: 10.58258/jupe.v10i2.8913.

[13] N. N. Le and M. Z. Aye, "The effect of integrating green sustainable science and technology into STEM learning on students' environmental literacy," *Integr. Sci. Educ. J.*, vol. 6, no. 3, pp. 232–239, 2025, doi: 10.37251/isej.v6i3.2116.

[14] D. Gil-Doménech and J. Berbegal-Mirabent, "Making the learning of mathematics meaningful: An active learning experience for business students," *Innov. Educ. Teach. Int.*, vol. 57, no. 4, pp. 403–412, Jul. 2020, doi: 10.1080/14703297.2020.1711797.

[15] M. Khalid, S. Saad, S. R. A. Hamid, M. R. Abdullah, H. Ibrahim, and M. Shahrill, "Enhancing creativity and problem-solving skills through creative problem solving in teaching mathematics," *Creat. Stud.*, vol. 13, no. 2, pp. 270–291, May 2020, doi: 10.3846/cs.2020.11027.

[16] J. Nilimaa, "New examination approach for real-world creativity and problem-solving skills in mathematics," *Trends High. Educ.*, vol. 2, no. 3, pp. 477–495, Jul. 2023, doi: 10.3390/higheredu2030028.

[17] S. Sahara, D. Juandi, T. Turmudi, A. Hendriyanto, L. H. Muhaimin, and M. D. Bulus, "Geometric reasoning to reinventing quadratic formula: The learning trajectory on realistic mathematics education principles," *Math. Teaching-Res. J.*, vol. 16, no. 3, pp. 164–196, 2024.

[18] H. M. Fajri, A. Marini, and Suyono, "Trends and patterns in realistic mathematics education research in elementary schools: A bibliometric approach," *Soc. Sci. Humanit. Open*, vol. 12, p. 101730, 2025, doi: 10.1016/j.ssaho.2025.101730.

[19] A. Soleha, D. K. Saputri, L. Saputri, and D. Hidayati, "Penerapan pendidikan matematika realistik untuk meningkatkan kemampuan pemecahan masalah matematika SD/MI," *J. Arjuna Publ. Ilmu Pendidik., Bhs. dan Mat.*, vol. 2, no. 6, pp. 352–361, Nov. 2024, doi: 10.61132/arjuna.v2i6.1361.
[20] M. Wahyudi, M. Joharman, and M. Ngatman, "The development of realistic mathematics education (RME) for primary schools' prospective teachers," in *Proc. Int. Conf. Teacher Training and Education (ICTTE 2017)*, Paris, France, 2017, doi: 10.2991/ictte-17.2017.83.
[21] K. Gravemeijer and M. Doorman, "Context problems in realistic mathematics education: A calculus course as an example," *Educ. Stud. Math.*, vol. 39, no. 1–3, pp. 111–129, Jun. 1999, doi: 10.1023/A:1003749919816.
[22] D. Nabila Junita and R. Dev Prasad, "The effect of using animation video on students' writing skills," *J. Lang. Lit. Educ. Res.*, vol. 1, no. 2, pp. 39–44, 2024, doi: 10.37251/jolle.v1i2.1063.
[23] M. C. Sirait and P. Ratti, "Building health awareness: Analysis of the relationship between knowledge and attitude with BSE behavior in public health science students," *J. Heal. Innov. Environ. Educ.*, vol. 1, no. 2, pp. 53–59, Dec. 2024, doi: 10.37251/jhiee.v1i2.1206.
[24] M. A. Miharja, M. Bulayi, and L. V. M. Triet, "Realistic mathematics education: Unlocking problem-solving potential in students," *Interval Indones. J. Math. Educ.*, vol. 2, no. 1, pp. 50–59, Jun. 2024, doi: 10.37251/ijome.v2i1.1344.
[25] I. N. Rohmah and A. Jupri, "The effectiveness of mathematics learning through a realistic mathematics education approach in elementary schools," *J. Cakrawala Pendas*, vol. 10, no. 3, pp. 500–511, Jul. 2024, doi: 10.31949/jcp.v10i3.9472.
[26] W. R. Tumangger, I. A. Khalil, and R. C. I. Prahmana, "The impact of realistic mathematics education-based student worksheets on improving students' mathematical problem-solving skills," *IndoMath Indones. Math. Educ.*, vol. 7, no. 2, p. 196, Aug. 2024, doi: 10.30738/indomath.v7i2.122.
[27] F. Amir, F. M. Firdaus, and A. Pada, "How does realistic mathematics learning shape learners' problem-solving and critical thinking skills?" *Al-Ishlah J. Pendidik.*, vol. 16, no. 3, Jul. 2024, doi: 10.35445/alishlah.v16i3.5101.
[28] R. Setyaningsih, H. Haryanto, and N. Rhosyida, "The effect of realistic mathematics education approach on students' critical thinking skills," *Aksioma J. Progr. Stud. Pendidik. Mat.*, vol. 10, no. 3, p. 1658, Oct. 2021, doi: 10.24127/ajpm.v10i3.3859.
[29] C. C. H. Yip, X. Ouyang, E. S.-K. Yip, C. K.-Y. Tong, and T. T.-Y. Wong, "Distinct roles of cognitive and mathematics skills in different levels of mathematics development," *Learn. Individ. Differ.*, vol. 119, p. 102645, Apr. 2025, doi: 10.1016/j.lindif.2025.102645.
[30] N. S. Mohd Rasid and S. Sahara, "Tech-enabled inclusive math education: Reimagining learning for marginalized Indonesian learners in Malaysia," *Lit. Int. J. Soc. Sci. Humanit.*, vol. 3, no. 1, pp. 155–177, 2024, doi: 10.52005/literate.v3i1.49.
[31] A. Wahyuni, N. A. Nasir, and M. Nurlita, "Epistemology of digital knowledge and axiology of technological literacy in elementary education toward an innovation ecosystem," *Lit. Int. J. Soc. Sci. Humanit.*, vol. 3, no. 2, pp. 194–210, 2024.
[32] A. N. Harahap, A. Bentri, E. Musdi, Y. Yerizon, and A. Armiati, "Analysis of students' critical thinking skills in solving mathematics problems in terms of students' initial ability," *Indones. J. Sci. Math. Educ.*, vol. 7, no. 1, p. 39, Mar. 2024, doi: 10.24042/ijsme.v7i1.18014.
[33] W. N. Yanuarto, E. Setyaningsih, A. Jazuli, and E. Suanto, "Mathematics education in the digital age: How to foster higher-order thinking skills?" *Int. J. Eval. Res. Educ.*, vol. 12, no. 4, p. 2045, Dec. 2023, doi: 10.11591/ijere.v12i4.24494.
[34] D. Farantika, N. N. Afrezah, Salhah, Saudah, Asiah, and E. Yafie, "Enhancing creative thinking in preschoolers: Teacher strategies for creating a multiliteracy-based learning environment," *JPUD – J. Pendidik. Usia Dini*, vol. 18, no. 1, pp. 232–250, Apr. 2024, doi: 10.21009/JPUD.181.17.
[35] I. Sofian, "Digital pedagogy and literacy development: The impact of ICT on reading comprehension in primary classrooms," *Lit. Int. J. Soc. Sci. Humanit.*, vol. 2, no. 1, pp. 41–56, 2023, doi: 10.52005/h8r4c231.
[36] E. Yi and D.-H. Park, "The effect of core competencies of university students on employment and first-year salary level," *Heliyon*, vol. 10, no. 7, p. e28474, Apr. 2024, doi: 10.1016/j.heliyon.2024.e28474.
[37] J. Joklitschke, B. Rott, and M. Schindler, "Notions of creativity in mathematics education research: A systematic literature review," *Int. J. Sci. Math. Educ.*, vol. 20, no. 6, pp. 1161–1181, Aug. 2022, doi: 10.1007/s10763-021-10192-z.
[38] S. N. Saindah, "The power of visual learning: Audio-visual health education to combat stunting in toddlers," *J. Heal. Innov. Environ. Educ.*, vol. 2, no. 1, pp. 68–75, 2025, doi: 10.37251/jhiee.v2i1.2008.
[39] W. Zahner, K. Tenney, K. Pelaez, and J. Choppin, "What is ambitious (mathematics) teaching? Clarifying a key concept in education research and practice," *J. Educ.*, Nov. 2025, doi: 10.1177/00220574251393976.
[40] A. Hendriyanto, D. Suryadi, S. Sahara, D. Fardian, I. Pauji, and L. H. Muhaimin, "From tools to thought partners: Optimizing technology as extended cognition for innovative didactic design," *AIP Conf. Proc.*, vol. 3220, no. 1, pp. 1–9, Oct. 2024, doi: 10.1063/5.0234677.
[41] R. Leikin and D. Pitta-Pantazi, "Creativity and mathematics education: The state of the art," *ZDM–Mathematics Education*, vol. 45, no. 2, pp. 159–166, Apr. 2013, doi: 10.1007/s11858-012-0459-1.
[42] A. Dominguez, "Teaching dynamics to enhance critical thinking and knowledge socialization in the mathematics classroom," *Frontiers in Education*, vol. 9, Aug. 2024, doi: 10.3389/feduc.2024.1388720.
[43] R. Richardo, et al., "Ethnomathematics augmented reality: Android-based learning multimedia to improve creative thinking skills on geometry," *International Journal of Information and Education Technology*, vol. 13, no. 4, pp. 731–737, 2023, doi: 10.18178/ijiet.2023.13.4.1860.
[44] F. K. Lawal, H. Isfa, and N. A. Hamid, "The influence of curiosity on students' critical thinking skills as viewed from the perspective of learning motivation in biology learning on cell material," *Journal of Academic Biology and Biology Education*, vol. 2, no. 1, pp. 88–96, 2025, doi: 10.37251/jouabe.v2i1.1913.
[45] J. I. Rotgans and H. G. Schmidt, "Interest in subject matter: The mathematics predicament," *Higher Education Studies*, vol. 4, no. 6, Nov. 2014, doi: 10.5539/hes.v4n6p31.

[46] A. Andriyatih, "Students' motivation to learn during the pandemic in the learning process from home," *Teaching English as a Foreign Language Overseas Journal*, vol. 11, no. 3, pp. 173–180, Dec. 2023, doi: 10.47178/hf5dp250.
[47] H. R. Hagad and H. Riah, "Augmented reality-based interactive learning media: Enhancing understanding of chemical bonding concepts," *Journal of Chemical Learning Innovation*, vol. 2, no. 1, pp. 52–59, 2025, doi: 10.37251/jocli.v2i1.1919.
[48] E. G. Rincon-Flores et al., "Improving the learning-teaching process through adaptive learning strategy," *Smart Learning Environments*, vol. 11, no. 1, p. 27, Jun. 2024, doi: 10.1186/s40561-024-00314-9.
[49] X. Lu and G. Kaiser, "Creativity in students' modelling competencies: Conceptualisation and measurement," *Educational Studies in Mathematics*, vol. 109, no. 2, pp. 287–311, Feb. 2022, doi: 10.1007/s10649-021-10055-y.
[50] R. Yusup, "Analyzing the role of information technology in enhancing teachers' attitudes towards e-learning: A case study in Indonesian higher education," *Literature International Journal of Social Sciences and Humanities*, vol. 2, no. 1, pp. 41–51, 2023, doi: 10.52005/rrkq1797.
[51] T. T. T. Linh, T. T. M. Huong, and N. Thammachot, "Sustainable nutrient management for NFT hydroponic lettuce: Integrating kipahit (Tithonia diversifolia) liquid organic fertilizer with AB-mix," *Integrated Science Education Journal*, vol. 6, no. 3, pp. 240–248, Sep. 2025, doi: 10.37251/isej.v6i3.2118.
[52] U. Hijriyah, M. Aridan, A. N. Mizan, A. Dealintang, and L. Yuniarti, "Development of digital comic media for learning Qira'ah for fifth grade students of Madrasah Ibtidaiyah," *Arabiyat: Jurnal Pendidikan Bahasa Arab*, vol. 6, no. 2, p. 693, Nov. 2022, doi: 10.29240/jba.v6i2.4361.
[53] L. H. Muhaimin, Y. S. Kusumah, D. Juandi, A. Hendriyanto, and S. Sahara, "The role of augmented reality-based media for enhancing students' mathematical ability: A systematic literature review," *AIP Conference Proceedings*, vol. 2909, 2023, doi: 10.1063/5.0182121.
[54] S. Pahmi, N. Priatna, Suhendra, and B. A. P. Martadiputra, "From learning to teaching: A study of mathematics academic and pedagogical anxiety in prospective elementary education teachers," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 21, no. 6, pp. 1–15, 2025, doi: 10.29333/ejmste/16512.
[55] D. N. Junita and R. D. Prasad, "The effect of using animation videos on students' speaking ability," *Journal of Language and Literature Educational Research*, vol. 1, no. 2, pp. 39–44, 2024, doi: 10.37251/jolle.v1i2.1063.
[56] Y. Kurniawan, "Motivation of class XI students towards learning physical education, sports, and health," *Multidisciplinary Journal of Tourism, Hospitality, Sport and Physical Education*, vol. 1, no. 1, pp. 16–20, Jun. 2024, doi: 10.37251/jthpe.v1i1.1038.
[57] G. P. Georgiou, "Mapping the ethical discourse in generative artificial intelligence: A topic modeling analysis of scholarly communication," *Language, Technology and Society*, vol. 3, no. 2, pp. 250–265, 2025.
[58] W. A. Aeni and A. Yusupa, "Model media pembelajaran e-komik untuk SMA," *Jurnal Kwangsan*, vol. 6, no. 1, p. 1, Jun. 2018, doi: 10.31800/jurnalkwangsan.v6i1.66.
[59] M. Berger, G. Michael, and N. Christoph, "E-comics: Pictorial learning media to train students' viewing skills," *Journal of Emerging Technology in Education*, vol. 1, no. 1, pp. 14–25, Jul. 2023, doi: 10.55849/jete.v1i1.188.
[60] U. Hijriyah, "How effective is SUNO.AI in enhancing Arabic listening skills? An evaluation of AI-based personalized learning," *International Journal of Information and Education Technology*, vol. 15, no. 2, pp. 391–407, 2025, doi: 10.18178/ijiet.2025.15.2.2251.
[61] A. Jatmiko, N. Armita, Irwandani, T. Saputro, and M. Aridan, "Development of science learning videos with the Canva application on socioscientific issues content," *E3S Web of Conferences*, vol. 482, p. 05004, Jan. 2024, doi: 10.1051/e3sconf/202448205004.
[62] E. N. Putri, M. Mahdavi, and M. S. Awlqadir, "An analysis of students' motivation and their achievement in learning English at the department of English education," *Journal of Language and Literature Education Research*, vol. 2, no. 1, pp. 43–50, Jun. 2025, doi: 10.37251/jolle.v2i1.1698.
[63] U. Abubakar, A. K. Soetan, and H. Ibrahim, "Integrating podcasting to enhance public speaking and pedagogical excellence of preservice language communication teachers in Ilorin public universities," *Language, Technology and Social Media*, vol. 3, no. 1, pp. 46–66, 2025.
[64] S. Rabani, A. Khairat, X. Guilin, and D. Jiao, "The role of technology in Indonesian education at present," *Journal of Computer Science Advances*, vol. 1, no. 2, pp. 85–91, Aug. 2023, doi: 10.55849/jsca.v1i1.403.
[65] C. Hao, A. Zheng, Y. Wang, and B. Jiang, "Experiment information system based on an online virtual laboratory," *Future Internet*, vol. 13, no. 2, p. 27, Jan. 2021, doi: 10.3390/fi13020027.
[66] K. Tulyani, "Health promotion analysis on gastritis: Students' knowledge and attitudes towards health," *Journal of Health Innovation and Environmental Education*, vol. 1, no. 1, pp. 26–31, Jun. 2024, doi: 10.37251/jhiee.v1i1.1026.
[67] N. Rina, J. R. Suminar, N. A. Damayani, and H. Hafiar, "Character education based on digital comic media," *International Journal of Interactive Mobile Technologies*, vol. 14, no. 3, p. 107, Feb. 2020, doi: 10.3991/ijim.v14i03.12111.
[68] F. R. Rasyid, T. A. R. P. Kesuma, and Karsiwan, "Design and development of flash-based learning media for enhancing students' learning interest," *Digital Learning in Social Science and Life Course Studies*, vol. 1, no. 1, pp. 52–67, 2025.
[69] M. Van den Heuvel-Panhuizen and P. Drijvers, "Realistic mathematics education," in *Encyclopedia of Mathematics Education*, Dordrecht: Springer, 2014, pp. 521–525, doi: 10.1007/978-94-007-4978-8_170.
[70] N. Diah, E. Elfis, and P. Titisari, "Development of learning media based on comic to increase students' learning outcomes at junior high school," in *Proceedings of the 2nd International Conference on Educational Development and Quality Assurance (ICED-QA 2019)*, Padang, Indonesia, 2019, pp. 1–6, doi: 10.4108/eai.11-9-2019.2298645.
[71] L. Junfeng, P. Vijayaratnam, and M. Shakiyeva, "Exploring the impact of individual differences on the knowledge construction process of Chinese college students," *International Journal of Learning, Teaching and Educational Research*, vol. 24, no. 6, pp. 543–561, 2025.

[72] A. Treffers, "Survey and justification," in *Three Dimensions: A Model of Goal and Theory Description in Mathematics Instruction*, Dordrecht: Springer, 1987, pp. 211–219, doi: 10.1007/978-94-009-3707-9_6.
[73] M. G. Bartolini, *Encyclopedia of Mathematics Education*, Dordrecht: Springer, 2014, doi: 10.1007/978-94-007-4978-8.
[74] R. Zou, L. Jiang, and W. Wider, "Bibliometric insights into the open education landscape," *International Review of Research in Open and Distributed Learning*, vol. 26, no. 1, pp. 283–309, 2025, doi: 10.19173/irrodl.v26i1.7953.
[75] M. S. Raharjo and A. Kumyat, "Analysis of driving factors for the implementation of clean technology to optimize green manufacturing in the Wiradesa batik small and medium enterprises," *Integrated Science Education Journal*, vol. 6, no. 3, pp. 258–268, 2025, doi: 10.37251/isej.v6i3.2115.
[76] C. E. Hmelo-Silver, "Problem-based learning: What and how do students learn?," *Educational Psychology Review*, vol. 16, no. 3, pp. 235–266, 2004, doi: 10.1023/B:EDPR.0000034022.16470.f3.
[77] A. Kumar, A. Vasudevan, D. Debyani, S. Nanda, and A. H. Rizvi, "Towards quality education: AI-supported English pedagogy in humanities and engineering for SDG implementation," *Journal of Engineering Education Transformations*, vol. 39, no. 1, pp. 65–75, 2025, doi: 10.16920/jeet/2025/v39is1/25135.
[78] N. Amlya, A. Majid, M. Fahmi, M. Amran, and A. Rauf, "Bridging the gap: The role of education and digital technologies in revolutionizing livestock farming for sustainability and resilience," *International Journal of Advanced Computer Science and Applications*, vol. 16, no. 5, pp. 483–493, 2025, doi: 10.14569/IJACSA.2025.0160547.
[79] F. Guo, C. Lin, and S. Akhter, "Autonomy and familiarity in AI-mediated collaboration: A self-determination theory perspective on motivational interdependence in EFL learners," *Learning and Motivation*, vol. 92, p. 102219, 2025, doi: 10.1016/j.lmot.2025.102219.