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Development of STEAM-Based E-Comic Using ADDIE Model: Enhancing Middle School Students' Learning Outcomes

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ABSTRACT

Purpose – This research aims to develop STEAM-based e-comics as an innovative digital learning medium through a water rocket-building project to improve learning outcomes for junior high school students.

Methodology – This study is a research and development (R&D) using the ADDIE model. Teachers and students from two Islamic junior high schools in Kudus Regency were involved in the analysis stage. The effectiveness test used a pretest-posttest one-group design with a research population of 370 seventh-grade students at an Islamic junior high school in Kudus Regency, Indonesia. The sample consisted of 30 students selected using random sampling techniques as the experimental group. The research instruments consisted of: 1) interview guidelines, 2) questionnaires, 3) pretest and posttest, 4) validation questionnaires, and 5) practicality questionnaires. Test data analysis used a paired sample t-test. Feasibility was determined from validation results by material experts, validation results by media experts, and questionnaire responses, using a percentage formula.

Findings – The study's results indicate that the developed STEAM-based e-comic is valid, practical, and effective. A score of 92.2% was obtained from material experts in the very feasible category, and 75% from media experts in the feasible category, both of which can be used with minor revisions. After the improvements were implemented, practitioners, as e-comic users, achieved a 95% score on the practicality test. The results of the effectiveness test indicate that the STEAM-based e-comic is effective for learning outcomes. This indicates that the developed STEAM-based e-comic significantly improves student learning outcomes.

Contribution – This research contributes to the integration of STEAM and digital media in education by providing empirically validated STEAM-based e-comic products. This study offers practical implications for teachers in the application of interdisciplinary learning media. Suggestions for future researchers include developing STEAM-based teaching materials for different materials and conducting larger-scale product trials.

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INTRODUCTION

In the current era, the use of digital media, such as e-comics, can help improve students' learning. Digital transformation in education requires teachers not only to adopt technology but also to integrate it pedagogically to align with learning goals. Past research has explored this topic, so providing knowledge about e-comics and other forms of digital media can improve student learning outcomes. Studies on English among Indonesian students showed significant improvements in learning outcomes after using e-comics (Arief et al., 2022). The use of e-comics has also been shown to increase students' motivation to learn science (Faria et al., 2024) and is an interesting medium for students (Safitri et al., 2021). Another study found that e-comics are more effective at conveying complex concepts more engagingly, thereby improving students' attitudes and learning outcomes (Mazid et al., 2024). E-comics and other digital media can be adapted for learning environments, both online and offline, making them versatile for diverse learning contexts (Hidayat & Soleh, 2023). However, most previous research has focused more on the effectiveness of media use; few have examined media development by integrating interdisciplinary content.

STEAM learning is designed to integrate multiple disciplines by fostering a holistic learning environment and enabling the cohesive application of knowledge across science, technology, engineering, art, and mathematics (Xue, 2022; Yim et al., 2024). STEAM encourages creativity, emotional expression, and a holistic understanding of interrelated disciplines (Zhao, 2025). STEAM education provides a wide range of benefits, including improved problem analysis and problem-solving skills (Juškevičienė et al., 2021), as well as promoting 21st-century skills such as collaboration, communication, and innovation, which are critical for success in modern education and careers (Zaqiah et al., 2024). However, the implementation of STEAM in learning practice still faces challenges in integrating media that connect interdisciplinary disciplines in concrete ways.

STEAM-based e-comics can introduce concepts in science, technology, engineering, art, and mathematics in an engaging way. The use of STEAM encourages interdisciplinary learning, integrating STEM with the arts (Bertrand & Namukasa, 2020), helping students understand concepts through creativity and fostering a more comprehensive educational experience (Khine & Areepattamannil, 2019; Marmon, 2019). The use of e-comics develops critical thinking and aesthetic understanding, as its activities focus on the visual arts. In addition, the design elements present in e-comics enhance the ability to interpret and analyze scientific content (Pantaleo, 2018, 2021). The use of STEAM-based e-comics can help students acquire knowledge in a more fun and relevant way. For example, learning math through e-comics helps students understand abstract concepts more visually and engagingly (Herlina et al., 2021). Based on this explanation, integrating e-comics with STEAM-based education has the potential to be an innovative medium that provides a high-quality learning experience for students.

Although e-comics offer many benefits, there is an assumption that using e-comics is time-consuming and impractical (Yunus et al., 2012) and that creating e-comics is time-consuming (Tekin & İlhan, 2025). These perceptions hinder the wider use of e-comics in classrooms. In addition, teachers' limited ICT skills and equipment pose a challenge to integrating technology into learning (Kibirige, 2023), including in the use and production of e-comics. The lack of systematic guidance related to media development is also an obstacle to producing high-quality products (Semerikov et al., 2025).

There have been several developments in e-comics and in STEAM studies, but few focus specifically on STEAM-based e-comics. A study highlighted the challenges in creating e-comics, including high production costs and limited materials (Shahul Hamid & Ghazali, 2021)However, it has not addressed a real problem in the field, namely the lack of learning media that integrate Mathematics and Science in a unified way through an applied project context, as identified in the needs analysis of teachers and students conducted at the partner school in this study. This research gap becomes even more pronounced given that studies explicitly explaining the theoretical relationship between e-comics and STEAM principles remain scarce; most prior research has treated e-comics and STEAM separately, without explaining how they can be integrated into a single learning

medium. This study is therefore important for filling that gap and advancing interdisciplinary learning in the classroom. The novelty of this study lies in the development of an e-comic that integrates all STEAM components into a single product, using a "water rocket making" project as a learning context that connects Mathematics and Science content in an integrated manner. This approach has not previously been examined in prior research. Accordingly, this study specifically aims to develop a STEAM-based e-comic for a water rocket project using the ADDIE model, and to examine its feasibility and effectiveness for the Mathematics and Science learning outcomes of grade VII students at junior high/Islamic junior high schools (SMP/MTs). Quality educational products will positively impact student learning outcomes, as shown by previous studies on the development of educational products that underwent expert validation and reported improvements in student learning outcomes (Hidayat & Soleh, 2023; Setyowati et al., 2023).

METHODOLOGY

This study is a Research and Development project aimed at developing STEAM-based e-comics to improve student learning outcomes at the junior high school level. Research design, participants, data collection techniques, instruments, and data analysis are explained as follows.

Research Design

This research uses the ADDIE model and follows a research-and-development approach. The ADDIE model has the potential to produce suitable educational products, as evidenced by its widespread use in the development of educational products (Budiarto & Roemintoyo, 2022; Damopolii et al., 2022). The structured stages of the ADDIE model ensure the production of high-quality products (Branch, 2009). This is because, by using the ADDIE model, experts conduct rigorous validation to ensure its effectiveness and suitability for educational purposes (Sumarmi et al., 2023; Wijaya et al., 2019). The steps taken in this study are: a) Analyze, b) Design, c) Develop, d) Implement, and e) Evaluate (Purwanto et al., 2023)

The first step is analysis. This stage involves identifying real conditions, conducting a needs analysis, and assessing feasibility. Analysis of real conditions includes examining the learning implemented, understanding and using STEAM by teachers, the use of learning media, and identifying students' experiences when involved in learning Mathematics and Science using technology-based learning media. Needs analysis, including the need to develop learning media, STEAM-based learning media, and technology-integrating media in Islamic junior high schools in Kudus Regency, Indonesia. The feasibility analysis includes a review of the scientific literature on the feasibility of using e-comic media to improve learning outcomes, the feasibility of using the STEAM approach for learning, and the supporting facilities at the research site, such as the availability of computers for learning.

The second step is design. The researcher designed a STEAM-based e-comic product with materials on mathematics and science subjects, namely plane and solid geometry and force, along with a project to build water rockets. At this stage, the researcher designs learning objectives, materials, e-comic sections, and storylines; plans STEAM components for e-comics; designs characters; collects necessary visual assets; and develops evaluation questions. The third step is development. At this stage, the existing design is developed into an e-comic product by integrating video links and validating with material and media experts. The fourth step is implementation. At this stage, the STEAM-based e-comic product is implemented in learning, carried out in grade VII at an Islamic Junior High School in Kudus, involving 1 teacher and 30 students. The practicality test was conducted by the teacher, who administered a questionnaire after students learned with STEAM-based e-comic products. The fifth step is evaluation. The evaluation assesses the product's effectiveness in learning. This stage involves testing the effectiveness of STEAM-based e-comics on mathematics and science learning outcomes.

Participant

The research has been conducted in one of the Islamic junior high schools in the Kudus Regency area, Central Java, Indonesia which has 370 grade VII students, by involving 4 teachers and 133 grade VII students at the analysis stage, as well as involving 1 teacher and 30 grade VII students, and involving 1 lecturer who is a material expert and 1 media expert at the development, implementation, and evaluation stages.

Data Collection

At the needs analysis stage, interviews are conducted to obtain an overview of the curricula used by schools, the learning strategies commonly employed, and teachers' understanding and application of STEAM. In addition to interviews, data were collected through questionnaires for teachers and students regarding media needs. Based on these findings, the media were designed using STEAM principles and in the form of e-comics. During the development stage, data are collected through a questionnaire to validate STEAM-based e-comic products with subject-matter and media experts. At the implementation stage, a practicality test was conducted through a questionnaire after practitioners used the developed STEAM-based e-comic product. During the evaluation stage, pretests and posttests are administered to students to assess the effectiveness of STEAM-based e-comic products.

Instrument

The instruments used are interview guidelines, questionnaires, and test questions. Interviews were used to collect data on teachers' needs for STEAM-based e-comic media. Questionnaire sheets are used to collect data on teachers' and students' needs, as well as assessment data from material and media experts and teachers. Test questions were used to collect data on learning outcomes before and after the use of STEAM-based e-comics. The test questions used to measure learning outcomes were first evaluated for content validity through expert judgment by lecturers in the fields of Mathematics and Science Education, and then trialed with 15 students outside the research sample to assess the validity of the question items using the product-moment correlation formula. At the same time, instrument reliability was assessed using Cronbach's alpha in IBM SPSS Statistics 25. The value of r_{hitung} consecutive is 0.706; 0.520; 0.706; 0.722; 0.653; 0.520; 0.654; 0.653; 0.654; 0.632. With n=15, the value of r_{hitung} were compared with the critical value ($r_{tabel} = 0.514$, α = 0.05) and declared valid. The reliability test yielded a Cronbach's Alpha of 0.823, indicating a high level of reliability. The question items declared valid and reliable are then used as pretest and posttest instruments during the evaluation stage.

Data Analysis

Test Data Analysis

The results of the pretest and posttest were analyzed using normality and homogeneity tests, and a paired-samples t-test. All analyses of the instrument trial and test results were carried out using Microsoft Excel and SPSS 22.

Non-Test Data Analysis

The data obtained through the questionnaire were analyzed using the following methods.

a. Needs analysis data

The needs analysis data obtained through the questionnaire is analyzed using the following formula.

$$Score = \frac{\sum x}{n}$$

Where $\sum x$ is the total score of all statements by respondents, and n is the sum of the maximum score of all statements. The results are then expressed as a percentage and categorized into Very Needed (80%-100%), Needed (60%-79%), Less Needed (40%-59%), and Not Needed (≤39%).

b. Feasibility Data

The results of the validation assessment from media experts, material experts, and practitioners were analyzed using the following formula (Simbolon et al., 2020).

$$P = \frac{\sum x_i}{\sum x} \times 100\%$$

Where P is the desired percentage score, $\sum x_i$ is the total score of each aspect, $\sum x$ is the maximum possible total score (ideal value), and 100% is a multiplier constant. However, product feasibility is determined using the intervals in Table 1 below.

Table 1. Product Feasibility Assessment Criteria

Scale	Percentage (%)	Interpretation
5	P ≥ 81%	Highly Feasible
4	61% ≤ P ≤ 80%	Feasible
3	41% ≤ P ≤ 60%	Quite Feasible
2	21% ≤ P ≤ 40%	Less Feasible
1	P ≤ 20%	Not Feasible

FINDINGS

This development research is carried out following the ADDIE development model, which includes Analysis, Design, Development, Implementation, and Evaluation.

Analysis

The analysis stage involves identifying real conditions, conducting a needs analysis, and assessing feasibility. At this stage, interviews were conducted with 2 science teachers and 2 mathematics teachers, followed by the completion of questionnaires by teachers and students. Based on the interview results, the curriculum used in schools is the "Merdeka" Curriculum. Learning is more often carried out through lectures, discussions, question-and-answer sessions, and models that use scientific approaches. Of the 4 teachers interviewed, 2 did not understand the STEAM concept, and only 1 had ever implemented STEAM-based learning. However, technology in learning is occasionally used, such as through videos, but not all students can benefit from it to the fullest. This is reflected in the results of an interview with one of the teachers (NSA):

> *"The learning media used are still limited, and students are not entirely optimal in receiving learning. There is a need for a variety of learning media. Students are more motivated when they know the material will be applied directly. Many students ask to use learning media."*(NSA)

Students need interesting learning media that lead to direct application of the material, foster motivation, and be varied. STEAM-based e-comics were chosen because they are easily accessible on a range of devices, including computers, laptops, and mobile phones. In addition, the products developed integrate various sciences, such as science, technology, engineering, the arts, and mathematics, and include projects that apply materials directly in everyday life. The e-comic format has never been used in school learning, so its use provides a variety of learning media. The use of STEAM in e-comics fosters creativity, critical thinking, communication, cooperation, and character development (Neldarisasmita et al., 2025). The availability of devices and internet access is a factor in the feasibility of this STEAM-based e-comic product, which warrants development. The teacher-completed needs questionnaire yielded the following results.

Table 2. Results of a questionnaire on the needs of teachers

	Strongly agree	Agree	Disagree	Strongly Disagree
Number of answers	26	47	7	0
Score Each Statement	4	3	2	1
Total scores	104	141	14	0
Total scores from respondents		259		
Maximum possible total score		320		
Percentage		80.94%		

Based on the calculations in Table 2, teachers feel that the development of STEAM-based e-comic media is very needed. Meanwhile, the needs questionnaire filled out by students obtained the following results:

Table 3. The Results of the Student Questionnaire

	Strongly agree	Agree	Disagree	Strongly Disagree
Number of answers	613	1412	530	105
Score Each Statement	4	3	2	1
Total scores	2452	4236	1060	105
Total scores from respondents		7853		
Maximum possible total score		10640		
Percentage		73.80%		

Based on the calculations in Table 3, students feel that developing STEAM-based e-comic media is needed.

Design

The STEAM-based e-comic design stage begins by setting learning objectives; defining materials, e-comic parts, and e-comic storylines; planning STEAM components for e-comics; designing characters; collecting necessary visual assets; and designing evaluation questions. E-comic is determined by material on mathematics and science subjects, namely plane and solid geometry, and force. The target users of the product are grade VII students at a secondary Islamic school in Kudus Regency. The language used is Indonesian, using daily conversation (not standard). E-comics are structured into 3 main sections: the Introduction, Core, and Closing. The Introduction section consists of the Cover, Instructions for Use, Introduction of the Characters, Table of Contents, Introduction, Learning Outcomes, Learning Objectives, and Synopsis. The Core Section consists of Rocket Assembling e-comic Reading, Let's Play (Student Worksheet), Practice Questions, Reading Materials, Evaluation, and Learning Videos (Let's Watch). The Concluding Section consists of an explanation of STEAM and a Bibliography. The STEAM-based e-comic aims to increase students' interest, motivation, and learning outcomes in Mathematics and Science at the Junior High School level.

The researcher determined a STEAM-based e-comic titled "Rakit Roket Air." To design each section, the researcher created a storyline. The Student Worksheet is delivered as a live worksheet, while the evaluation questions use the Quizziz application to be interactive and provide immediate feedback. The researcher used the Canva Pro application to design a STEAM-based e-comic, which was then saved as a PDF. The STEAM-based e-comic design process "Rakit Roket Air" is shown in Figure 1 below.

Figure 1. STEAM-Based E-Comic Design Process

Development

The development stage involves converting the design from a PDF into a website within the Heyzine flipbook application, allowing the product to be accessed digitally as an e-comic. This is followed by validation testing by material and media experts.

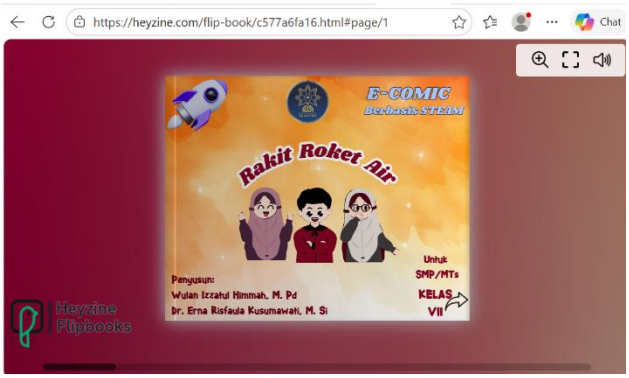


Figure 2. STEAM-Based E-Comic Draft Uploads on the Heyzine Flipbook Application

Material validation was carried out by an expert lecturer in the fields of Mathematics and Science using a questionnaire instrument employing a 1–4 scale, consisting of eight assessment aspects: material suitability with the curriculum, depth of material, scientific accuracy, the material's relationship to the concept of STEAM, language and term suitability, ease of understanding, relevance to everyday life, and creativity and innovation in presentation. The validators' assessment results are shown in Table 4.

Table 4. Validation Test Results by Subject Matter Experts

No	Indicator	Number of statement items	Average	Percentage	Description
1	Material Suitability with the Curriculum	2	4	100%	Highly Feasible
2	Depth of Material	2	3	75%	Feasible
3	Scientific Accuracy	2	4	100%	Highly Feasible

No	Indicator	Number of statement items	Average	Percentage	Description
4	Material's Relationship to the Concept of STEAM	2	3	75%	Feasible
5	Language and Term Suitability	2	4	100%	Highly Feasible
6	Ease of Understanding	2	3.5	87.5%	Highly Feasible
7	Relevance to Everyday Life	2	4	100%	Highly Feasible
8	Creativity and Innovation in Presentation	2	4	100%	Highly Feasible
	Total		29.5	92.2%	Highly Feasible
	Average		3.69	92.2%	Highly Feasible

Based on Table 4, the developed STEAM-based e-comic obtained an overall average score of 92.2%, placing it in the highly feasible category. All eigt aspects scored within the feasible to highly feasible range, with the highest scores (100%) recorded for curriculum suitability, scientific accuracy, language and term suitability, relevance to everyday life, and creativity and innovation in presentation. The lowest scores were obtained for material depth and the material's relationship to the STEAM concept, each at 75%, indicating a need to strengthen content elaboration and more clearly explain how the STEAM components are interconnected within the e-comic. These findings suggest that the developed product is substantially feasible in terms of content quality, although there is room to deepen the material and strengthen STEAM integration.

Table 5. Validation Test Results by Media Experts

No	Indicator	Number of statement items	Average	Percentage	Description
1	Visual and design	2	3	75%	Feasible
2	Compatibility with Target Users	2	3.5	87.5%	Highly Feasible
3	Integration of Media with Materials	2	3	75%	Feasible
4	Ease of Navigation	2	4	100%	Highly Feasible
5	Interactivity	2	2	50%	Quite Feasible
6	Creativity and Innovation in Presentation	2	2.5	62.5%	Feasible
7	Technical Quality	2	3	75%	Feasible
8	Conformity with Digital Learning Principles	2	3	75%	Feasible
	Total		24	75%	Feasible
	Average		3	75%	Feasible

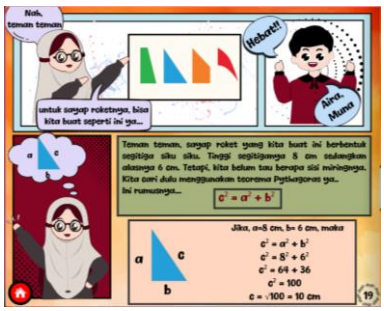
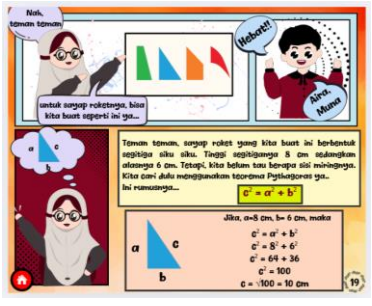
Based on Table 5, the developed STEAM-based e-comic obtained an overall average score of 75%, placing it in the feasible category. The highest score was recorded for ease of navigation (100%), while the lowest score was obtained for interactivity (50%), which fell into the quite feasible category. This indicates that interactivity, along with creativity and innovation in presentation (62.5%), were the main focus for product improvement prior to implementation, as subsequently addressed through Focus Group Discussion (FGD).

After the validation test, the next activity was a Focus Group Discussion (FGD). During the FGD, the resource persons presented the validation results and provided input on the developed STEAM-based e-comic products. One of the speaker's inputs concerned the selection of colors and navigation buttons. Participants

also provided input on the e-comics that had been created. These inputs include displaying several parts and writing formulas in the material to make it clearer and easier to read.

The e-comic is then improved based on input and suggestions from material experts, media experts, practitioners, and FGD participants. The revision and improvement efforts for the STEAM-based e-comic are shown in Table 6 below.

Table 6. Before and After E-comic Repair

No.	Before Repairs	After Repairs
1.		
2.		
3.		
4.		

5.

6.

Implementation

The fourth stage of ADDIE's design is implementation. At this stage, STEAM-based e-comic products that have been declared suitable for use are then tested for teachers and grade VII students. The trial aims to determine the teacher's assessment after using the STEAM-based e-comic product developed. Products that have been validated, with suggestions for improvement from validators, are then tested for practicality. The results of the STEAM-based e-comic practicality test are shown in Table 7.

Table 7. A Summary of the Results of the Practical Test

No	Indicator	Number of statement items	Average	Percentage	Description
1	Ease of use	4	4	100%	Highly Feasible
2	Suitability of learning materials	4	3.75	93.75%	Highly Feasible
3	Visual appeal and design	4	3.5	87.5%	Highly Feasible
4	Interactivity and student engagement	4	4	100%	Highly Feasible
5	Efficiency in learning	4	3.75	93.75%	Highly Feasible
	Total		19	95%	Highly Feasible
	Average		3.8	95%	Highly Feasible

Based on Table 7, all practicality aspects fell into the highly feasible category, with the highest scores for ease of use, interactivity, and student engagement (100% each). The overall average score of 95% indicates that the STEAM-based e-comic, revised based on input from the validators and FGD participants, was rated as highly practical for use by teachers and students in Mathematics and Science learning in grade VII.

Evaluation

The evaluation stage in ADDIE assesses the product's success in the learning process. After the STEAM-based e-comic is used as a medium in the learning process, an evaluation test stage is carried out in the form of a test of the effectiveness of the STEAM-based e-comic on the cognitive learning outcomes of Mathematics subjects on plane and solid geometry materials, as well as science subjects of Force material, especially in the Newton's Law section. The initial ability of students, as shown by the pretest, had an average score of 60, while the learning outcomes, as shown by the posttest, had an average score of 74. Pretest and posttest scores were analyzed using a paired-samples t-test to determine the effectiveness of product use. The results of the paired-samples t-test are shown in Table 8.

Table 8. Hypothesis Test Results

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Pretest - Posttest	-14.000	10.034	1.832	-17.747	-10.253	-7.642	29	.000

Based on the results of the paired sample t-test, a significance value of 0.000 and t_{value} of -7.642. It can be concluded that a STEAM-based e-comic is effective in improving the learning outcomes of grade VII Junior High School students.

DISCUSSION

The development of STEAM-based e-comics for mathematics and science subjects uses the ADDIE development model. The first stage is the analysis stage, which includes a need and feasibility analysis. The needs analysis is based on the problems faced by mathematics teachers and science teachers, as well as students at Junior Islamic Schools in Kudus Regency. The problem successfully explored was the need for a variety of learning media and the direct application of materials in learning, which led students not to absorb the material optimally. Therefore, varied learning media and the direct application of the material are important for increasing interest and motivation, thereby enabling optimal student learning outcomes. STEAM-based e-comics are selected based on the results of the need and feasibility assessments. E-comics offer various advantages over traditional print comics, including interactive features such as sound effects and the ability to engage with the comic's content, which allow users to choose specific parts that traditional comics cannot (Ontenient Lledó, 2025). An interactive, visually appealing e-comic format can enhance the learning experience. E-comics can also be used more flexibly, as they can be accessed anytime, anywhere (Safitri et al., 2021). The existing literature confirms the effectiveness of e-comics in increasing motivation to learn (Ramadana & Widayati, 2025) and student achievement, making them an effective learning tool (Apostolou & Linardatos, 2023). Meanwhile, the STEAM approach was chosen for its benefits across cognitive, affective, and practical domains. STEAM fosters creativity, critical thinking, problem-solving, and teamwork, which are essential for 21st-century challenges (Mynbayeva, 2025). STEAM fosters curiosity and motivation, particularly through hands-on and project-based learning approaches (Behera et al., 2025)

The second stage is design, which involves planning STEAM-based e-comic content, including determining learning objectives, materials, e-comic parts, and e-comic storylines; planning STEAM components in e-comics; designing characters; collecting necessary visual assets; and designing evaluation questions. The STEAM-based e-comic is designed to use non-standard Indonesian to resemble students' daily conversations. The story context in the e-comic is a school setting, featuring four students and a storyline about building a water rocket. In the storyline for the water rocket project, instructions for building a water rocket are included, along with mathematics and science materials related to its manufacture. The STEAM

components used include Science (motion and force, Newton's Law III, and pressure), Technology (simple technology of making water rockets and launching water rockets), Engineering (designing and making water rockets based on the design that has been made, operating a water rocket), art (creation of the shape and color of water rocket parts), and mathematics (calculation of the size of water rocket parts, plane and solid geometry). The selection of the water rocket project as the design context was grounded in the principle of situated learning, which holds that learning is most effective when concepts are taught within the context of their use, thereby rendering the resulting knowledge relevant and directly applicable to real-life situations (Catalano, 2015; Kulkarni et al., 2024). This e-comic is designed to make it easier for students to apply the creation of water rockets directly, providing a real experience. Creation videos and supporting materials are also included in the e-comic to clarify the creation process and deepen the material. The use of visual media plays an important role in improving the understanding of abstract concepts (Hindriana et al., 2026; Qohar et al., 2025).

The third stage is the development stage, which continues the design process by producing a STEAM-based e-comic product ready for use and upload to the heyzine flipbook application. Expert validation was conducted to ensure the feasibility of the products carried out by material experts and media experts. The validation process involves multiple experts to ensure a comprehensive evaluation is conducted across multiple dimensions. The material expert's validation yielded a score of 92.2% in the Very Feasible category, while the media expert's validation scored 75% in the Feasible category, requiring revision based on input. Input was given regarding color selection, navigation buttons, and formula writing. Improvements were made based on input from validators and FGD participants to produce a STEAM-based e-comic with better color display, more readable formula writing, and functional navigation buttons. The notable gap between the material and media expert validation scores, particularly the low score for interactivity (50%), indicates that the product's primary strength lies in content quality and curriculum alignment. In contrast, the technical and interactive dimensions of the digital media remain weaknesses that warrant greater attention when developing similar products in the future. The use of flipbooks is known to improve the presentation of dynamic and interactive mathematical concepts, as well as improve students' understanding (Putri et al., 2025), however, this platform's limitation, namely its dependence on a stable internet connection (Anwar et al., 2025)It restricts the product's accessibility in school environments if internet access remains limited.

The fourth stage is implementation. Products that have been declared suitable for use and have undergone a revision process are used in grade VII learning as a limited trial. Furthermore, teachers assess the practicality of STEAM-based e-comics, including ease of use, suitability of learning materials, visual appeal and design, student interactivity and engagement, and learning efficiency. Based on the practicality test questionnaire, a score of 95% was obtained, indicating that the product is highly feasible or practical. This means that STEAM-based e-comics developed can be used for learning. This aligns with Gunadi's (2023) view that the developed product is easy to use. Nevertheless, the practicality score in this study was based on a single teacher's assessment as the sole practitioner, so generalizing these findings to broader acceptance among teachers would require testing with a larger sample of teachers.

The fifth stage is evaluation. Field evaluation is essential to determine the effectiveness of the STEAM-based e-comic. The effectiveness of STEAM-based e-comics can be found by comparing students' pretest and posttest results. The pretest and posttest scores were tested with a paired sample t-test, with the results of the t-value calculated > t_{table}, namely -7.642 > -2.045 with a significance value (Sig.) of 0.000 < 0.05, then it can be stated that the STEAM-based e-comic is effective on the learning outcomes of grade VII MTs students. The significance of this improvement in learning outcomes is consistent with prior findings that presenting verbal and visual information simultaneously can reduce extraneous cognitive load and enhance learning outcomes (Hindriana et al., 2026). In relation to the STEAM-based e-comic in this study, a similar mechanism is presumed to apply to the delivery of content through visual and verbal elements — namely, images and accompanying text — although a direct test of reduced extraneous load was not conducted. In addition, the water rocket project, which integrates all STEAM components, provided a concrete and meaningful learning

experience, enabling students not only to memorize concepts but also to directly experience their application, thereby contributing to the improvement in learning outcomes observed in this study. The results of this study align with those of Gunadi et al. (2023), who developed an e-comic as a learning medium for Islamic Education in elementary school students. The e-comic developed is effective in helping students' understanding and interest. Another related study is that of Tuzuhro et al. (2024), which examined the development of character-based digital comics in economics. The digital comic helps improve the cognitive learning outcomes of Senior High School students. However, not all prior findings share the same focus. Sihombing et al. (2025), who developed an e-comic for IPAS learning, reported a very high N-Gain of 0.88 in student learning interest. This figure reflects an affective outcome rather than cognitive achievement. It is therefore not directly comparable to the effect size obtained in the present study, which specifically measured cognitive learning outcomes. This difference reveals a broader pattern in the e-comic development literature: several studies report successful use of e-comics not only for cognitive outcomes but also for affective outcomes.

This study has several limitations. First, the relatively small sample size of 30 students from a single school limits the generalizability of the findings to a broader population. Second, the one-group pretest-posttest design employed did not include a control group, meaning that the observed improvement in learning outcomes cannot be fully attributed to the intervention itself, as no comparison group without the STEAM-based e-comic was available to rule out the influence of other factors. Third, the product's implementation was limited to a small-scale trial of relatively short duration and therefore does not capture the long-term impact of using the STEAM-based e-comic on student learning outcomes.

These findings carry theoretical implications by reinforcing the framework for integrating STEAM and digital media in interdisciplinary learning, as well as practical implications for Mathematics and Science teachers in schools with similar characteristics, who may consider adopting the STEAM-based e-comic as a contextual and applicable alternative learning medium. More broadly, these results are relevant to the demands of the Kurikulum Merdeka (Indonesia's Independence Curriculum), which promotes project-based learning and the strengthening of 21st-century skills such as critical thinking, creativity, collaboration, and digital literacy among students.

CONCLUSION

The study concluded that the developed STEAM-based e-comic products are feasible. This is shown by the validation conducted by the material expert, which yielded a score of 92.2% and a very feasible category. Validation by media experts yielded a score of 75%, placing it in the feasible category. The practitioner's practicality test yielded a score of 95%, placing it in the very feasible category. The results of implementing STEAM-based e-comics using a one-group pretest-posttest design showed a significant value (sig.). = 0.000 < 0.05, indicating that STEAM-based e-comics are effective in improving the learning outcomes of mathematics and science students in grade VII Junior High School. This shows that the use of digital media, especially STEAM-based e-comics, improves student learning outcomes. Furthermore, this development research successfully integrated all STEAM components into a single e-comic product. This comprehensive integration required that content be designed as an interconnected whole within a coherent storyline, rather than as standalone pieces. Using a water rocket-making project as the learning context was a key element that linked mathematical and scientific concepts in a concrete, applicable way. This study strengthens integrated Mathematics and Science learning through a single medium, aligning with the principle of interdisciplinary learning, which emphasizes the interconnectedness of different disciplines. This study also contributes to the development of 21st-century digital learning relevant to the demands of the Kurikulum Merdeka, while simultaneously honing 21st-century skills such as critical thinking in understanding concepts, creativity in following the water rocket project storyline, and problem-solving through an integrated STEAM approach. The results of this research can serve as a reference for teachers in developing and implementing STEAM-based learning media. It is suggested that future researchers consider developing STEAM-based teaching materials for different materials, conducting larger-scale product trials, and using more robust experimental

designs. Testing other variables, such as 21st-century skills, is also important to enrich the empirical evidence on the effectiveness of STEAM-based e-comic media.

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