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Development of E-Comic-Based Teaching Module to Enhance Students' Mathematical Argumentation Skills

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Abstract: This study aims to develop an e-comic-based teaching module to enhance students' mathematical argumentation skills on the topic of Systems of Linear Equations in Two Variables (SPLDV), referring to the Toulmin Argumentation Framework (data, claim, warrant, backing, rebuttal, and qualifier). The study employed a Research and Development (R&D) design using the ADDIE development model. It was conducted at one of the public junior high schools in Jombang, East Java, Indonesia, involving 25 students and two teachers as respondents. The research instruments included expert validation sheets, questionnaires for teachers and students, and a mathematical argumentation skills test developed based on the elements of the Toulmin framework. The effectiveness was evaluated using a one-group pretest–posttest approach, in which all participants were given mathematical argumentation tests before and after learning with the e-comic module. Data were analyzed using a paired sample t-test with SPSS to determine significant differences between the pre-test and post-test results. The expert validation results showed that the e-comic-based module obtained an average score of 94.23%, categorized as very valid, indicating strong content alignment, instructional design quality, and classroom applicability. The practicality test revealed that teacher responses averaged 94% and student responses 82%, both categorized as very practical, demonstrating that the module is easy to use, engaging, and relevant to students' learning needs. The effectiveness test yielded a significance value of 0.000 (< 0.05), which reflects the module's potential to enhance students' mathematical argumentation skills. Pedagogically, the integration of the Toulmin framework in the e-comic context effectively helps students construct logical, structured, and evidence-based mathematical arguments through contextual narrative visualization. This approach also enhances students' motivation, engagement, and reflective thinking during the learning process. Therefore, the developed e-comic-based teaching module is valid, practical, and effective in improving students' mathematical argumentation skills and in supporting active, reflective, and meaningful mathematics learning.

Keywords: teaching module, digital technology, e-comic, mathematical argumentation skills.

▪ INTRODUCTION

Education in the 21st century requires students not only to master general knowledge but also to possess critical, creative, collaborative, and communicative thinking skills (Nahdi, 2019). Quality education must foster higher-order thinking skills, enabling learners to solve various life challenges (Masjudin, 2024). One of the core subjects in the national curriculum is mathematics (Rafianti et al., 2018). Mathematics plays a crucial role in developing logical and systematic thinking skills. However, mathematics is still considered difficult and boring by most students. In addition, the lack of varied methods and limited use of learning media often make mathematics learning appear monotonous and less creative, causing students to perceive it as difficult and uninteresting (Alawiyah, 2022). This is due to the abstract nature of the material, the lack of concreteness, and the limited variety of engaging instructional media. In the context of

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mathematics learning, argumentation skills are crucial for helping students develop strong logical reasoning, clear perspectives, and rational explanations (Siregar et al., 2019).

Studies by Metaxas (2015) and Lin (2018) indicate that students' engagement in technology-based mathematics projects can significantly enhance the density and quality of their mathematical argumentation elements. However, studies that specifically investigate how e-comic-based media or other forms of multimodal digital learning can strengthen students' mathematical argumentation skills, such as constructing claims, presenting evidence, and formulating rebuttals, remain very limited (Corneli et al., 2019; Francisco, 2022). Moreover, research shows that teachers' ability to facilitate mathematical argumentation processes, including their understanding of mathematical knowledge for teaching, is a key factor in developing students' argumentative practices in the classroom (Francisco, 2022).

A person's argumentation ability is generally reflected in how students present their reasoning, both orally and in writing (Tristanti & Nusantara, 2021a). In solving mathematical problems, students are expected to provide explanations based on available data and supporting theories, orally or in writing, to demonstrate their understanding of mathematical concepts. Such arguments are used to generate, justify, and support reasonable solutions. However, some students are unable to express arguments effectively (Tristanti & Nusantara, 2021b). In mathematics learning, the development of argumentation skills requires transforming non-deductive arguments into deductive arguments (Tristanti et al., 2016). Argumentation is defined as an activity that coincides with proof or justification. However, it is a broader concept and is perceived as a crucial component in learning mathematics (Staples et al., 2012).

The development of argumentation skills in mathematics learning can be strengthened through the use of technology. Digital tools and media create interactive environments where students can articulate their reasoning, assess arguments, and organize evidence in a structured way. Beyond serving as visualization aids, technology also acts as a collaborative space that promotes critical, creative, and reflective thinking in tackling mathematical problems (Jupri, 2018; Murtiyasa, 2012; Najjar, 1998; Tristanti et al., 2024a). Consequently, incorporating technology into mathematics instruction plays a crucial role in fostering a learning environment that nurtures students' mathematical argumentation skills.

The rapid development of digital technology presents new opportunities for creating learning strategies that utilize interactive and engaging media formats. One such innovative medium is the use of e-comic-based instructional modules. E-comics, which combine digital visuals and narrative storytelling, are effective in capturing students' interest and enhancing their understanding of concepts through relevant, contextual illustrations (Rezky et al., 2024). In mathematics education, e-comic modules function not only as entertaining learning tools but also as instruments to cultivate students' critical thinking and mathematical argumentation abilities. Through the depiction of story-driven conflicts, dialogues, and character-based problem-solving, learners are encouraged to reflect on the material, build logical arguments, and express their mathematical reasoning (Wijayanto et al., 2022). Several studies have shown that digital comics (e-comics) hold great potential for enhancing students' higher-order thinking skills in mathematics learning. Cahyono et al. (2025) found that religious value-based mathematical e-comics improved students' critical thinking skills in geometry, while Darmayanti (2022) reported

that character-based digital comics effectively fostered critical thinking in problem-solving. Fitriani & Leton (2024) emphasized that e-comics applying the Realistic Mathematics Education (RME) approach can increase students' learning interest, and Farhan et al. (2024) demonstrated that culturally based e-comics significantly enhanced students' motivation and learning outcomes. Similarly, Saragih & Siregar (2025) showed that e-comics grounded in realistic mathematics approaches deepen conceptual understanding. Meanwhile, Lehmann & Friend (2025) highlighted, through a systematic review, that argumentative practices in mathematics education remain underexplored despite their crucial role in developing higher-order reasoning. Rusyid et al. (2024) further emphasized the importance of strengthening mathematical reasoning and argumentation through innovative learning strategies. Based on these findings, limited research has specifically examined the effectiveness of e-comics in enhancing mathematical argumentation skills; therefore, the study E-Comic-Based Teaching Module to Enhance Students' Mathematical Argumentation Skills contributes new insights by focusing on students' ability to construct claims, provide mathematical evidence, and develop logical reasoning within the context of learning Systems of Linear Equations in Two Variables (SPLDV).

Mathematical argumentation skills are a key aspect of mathematical reasoning, as they enable students to construct, justify, and evaluate claims using evidence and logical reasoning. These skills not only help students arrive at correct answers but also enable them to understand and explain the rationale behind them, aligning with 21st-century skills such as critical thinking, problem-solving, and effective communication (Renninger et al., 2023).

In the context of mathematics education, the Toulmin Argumentation Framework (TAF) is employed as a model to systematically analyze and guide the structure of students' arguments. Toulmin (2003) identifies six main components: data, claim, warrant, backing, qualifier, and rebuttal, which allow students to connect evidence with conclusions, provide justifications, and consider counterarguments. Previous studies indicate that students often struggle particularly with the warrant and rebuttal components, requiring explicit guidance in developing mathematical arguments (Syahar et al., 2025; Tristanti et al., 2017). Figure 1 presents the framework of mathematical argumentation based on the Toulmin Argumentation Model (Inglis et al., 2007).

The advancement of technology and the demands of 21st-century learning have made digital media a strategic tool to enhance engagement and conceptual understanding (Fitria et al., 2023; Mayer, 2014). Digital comics (e-comics) serve as an innovative medium that presents problem contexts visually, narratively, and interactively, helping students understand abstract mathematical concepts and construct mathematical arguments more systematically (Oliwe & Chao, 2022). The implementation of e-comics in teaching systems of linear equations in two variables (SPLDV) allows students to explore various scenarios, formulate data, construct claims, and review counterarguments in an engaging and contextually relevant way (Abrori et al., 2024; Manalo, 2024).

One mathematical topic well-suited to this approach is the system of linear equations in two variables (SPLDV), a part of the junior high school curriculum that integrates real-life situations and can be addressed using mathematical modeling (Kemendikbud, 2017). This topic trains students to analyze problems, construct models, solve mathematical models, and recheck solutions. These steps are processes inherent in

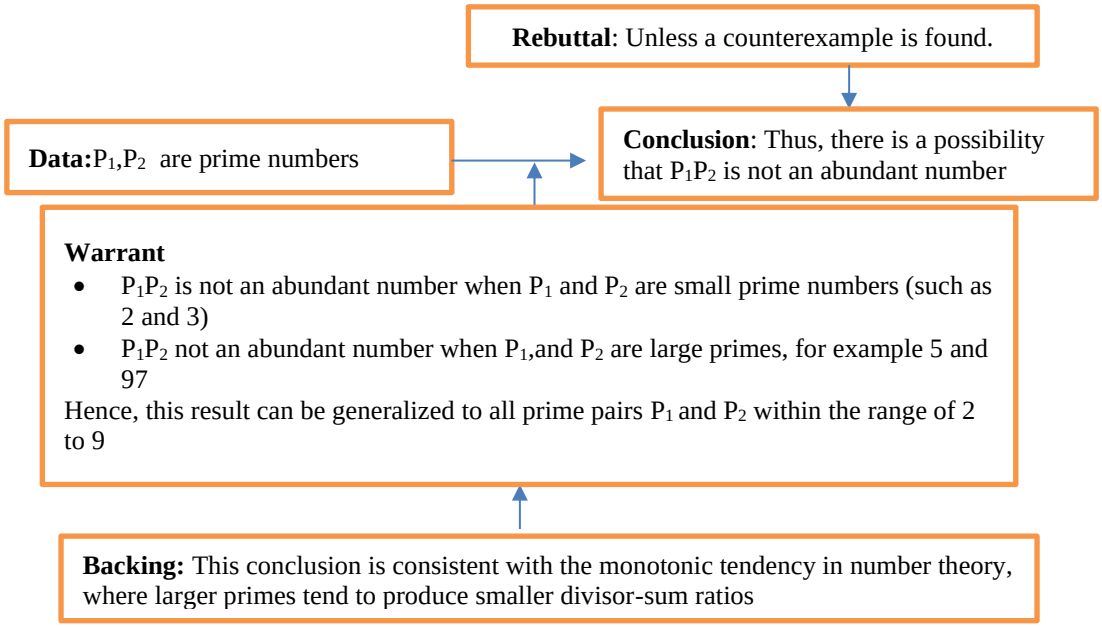

Figure 1. Mathematical argument based on the toulmin model

mathematical argumentation (Alviyah & Asyhar, 2023; Stylianides, 2008). However, SPLDV is considered a challenging topic because it requires understanding algebraic concepts, symbolic representation, and problem-solving (Solikha & Rahaju, 2025). Therefore, instructional media that present the material in a visual story format are needed to capture students' interest, reduce boredom, and increase learning motivation. Comics, as an art form consisting of panels arranged to form a storyline with character dialogues presented in speech balloons, serve this purpose well (Febriyandani & Kowiyah, 2021; Toh et al., 2017).

The integration of e-comics into structured and systematic mathematics instruction is still relatively uncommon. This e-comic module stands out from existing digital mathematics comics by systematically incorporating Toulmin's six components of argumentation (data, claim, warrant, backing, qualifier, and rebuttal) into the narrative structure. This approach enables students to construct and evaluate mathematical arguments in a structured manner, aligning with best practices in argumentation-based learning (Groth, 2024; Reuter, 2023). Unlike traditional e-comics that focus primarily on concept delivery, this module emphasizes critical components such as warrant and rebuttal, which are often underdeveloped in students' reasoning processes (Zengin & Broutin, 2025). By embedding two-variable linear equations within interactive, real-life contexts, the module fosters 21st-century skills such as critical thinking, problem-solving, and effective communication (Assadi, N., & Hibi, 2022).

Moreover, this module provides empirical evidence of its effectiveness in enhancing students' argumentation skills, a feature rarely addressed in other digital mathematics comics (Çiçek Şentürk & Selvi, 2024). Developing a teaching module based on e-comics is therefore essential to provide learning materials that are innovative, engaging, and effective. Such a module supports students' competencies in understanding and solving problems related to systems of linear equations in two variables. This study examines how and why the e-comic-based module affects students' mathematical

argumentation skills, aiming to investigate the mechanisms and effectiveness of helping students construct, justify, and evaluate mathematical arguments.

▪ METHOD

Participants

The participants of this study were drawn from a public junior high school in Indonesia. A total of 25 students and two teachers took part in the research. The students were from a single class that was purposefully selected based on their accessibility and relevance to the study objectives. The two teachers involved were responsible for teaching mathematics and acted as facilitators during the implementation of the learning media. All participants voluntarily participated in the study and were informed about its purpose and procedures.

Research Design and Procedures

This study employed a Research and Development (R&D) approach, designed to create and evaluate the viability of a specific product (Sugiyono, 2018). The outcome of this research was the creation of a mathematics teaching module based on e-comics, intended to enhance students' skills in mathematical argumentation. To develop the instructional module, the study applied the ADDIE model, which includes five key stages: Analysis, Design, Development, Implementation, and Evaluation. This model was selected because it offers a structured and iterative process, where each phase involves assessment and refinement to ensure the final product meets validity standards. As an instructional design framework, ADDIE supports the systematic creation of educational content suitable for both traditional classroom settings and online learning environments.

The ADDIE model is widely regarded as an efficient and reliable framework for developing educational products, offering a thorough and structured approach to instructional design (Wandari, 2018). The specific tasks involved at each stage are outlined as follows. The Analysis Stage was carried out before the development of the e-comic-based teaching module. It involved identifying challenges in mathematics instruction, reviewing the curriculum in relation to its specific features, and assessing the necessity of an e-comic-based module to enhance students' abilities in mathematical argumentation. The Design Stage focused on developing learning indicators aligned with the Basic Competencies (KD) related to the topic of Systems of Linear Equations in Two Variables (SPLDV), as well as preparing tools to assess the feasibility of the learning module. In this phase, the researcher developed an e-comic–based learning module and designed supporting research instruments, including expert validation sheets, interview guidelines, and achievement tests.

The development of the e-comic was guided by design principles grounded in argumentation theory, particularly Toulmin's Argumentation Model, to ensure that the media not only provided visual engagement but also effectively fostered students' argumentative thinking. In this regard, every visual and narrative component was required to maintain conceptual coherence, ensuring relevance to the mathematical ideas being taught. The storyline and dialogues were structured to explicitly represent the argumentative process, displaying the relationship among data (evidence), claim (statement), and warrant (logical reasoning). Additionally, conflicts and problem situations embedded within the narrative were intentionally designed to prompt cognitive interactivity, encouraging students to construct their own mathematical arguments.

Finally, the integration of visual and narrative elements was organized to flow logically and coherently, supporting a clear and structured sequence of argumentation throughout the comic.

In terms of dialogue design, each character in the e-comic plays a distinct role in the argumentative narrative. The main character serves as the claim maker, proposing mathematical ideas or solutions. Supporting characters act as data providers, presenting relevant calculations or factual information. The teacher or peer character provides the warrant, explaining the logical connections between data and claim, and occasionally adds backing in the form of theoretical or conceptual support. Meanwhile, other characters may present rebuttals to challenge or test the strength of the argument being made.

From the perspective of visual panel design, the comic's structure is organized to explicitly represent the components of an argument. The first panel typically introduces the problem situation (context and data). The following panels present the claim or proposed solution, and subsequent panels show the warrant, which bridges the logical relationship between the data and the claim. Additional panels may include backing in the form of conceptual references or rebuttals as a means of critical reflection on the proposed solution.

By applying these principles, the e-comic is expected to function not only as an educationally engaging medium but also as a visual representation tool of mathematical argumentation processes, helping students understand how mathematical conclusions are constructed logically and supported by evidence.

The development stage involved validation of the e-comic-based teaching module by both media experts and subject-matter specialists. This process included several steps: constructing the e-comic-based instructional module focused on SPLDV content, conducting validation using instruments such as expert validation forms, student and teacher feedback questionnaires, and a test designed to assess mathematical argumentation skills, and refining the module and research instruments based on the feedback and findings obtained during the validation phase.

The Implementation Stage was carried out in mathematics learning of SPLDV at one of the public junior high schools in Jombang, East Java, Indonesia. Teachers and students were asked to complete questionnaires to assess the developed module. The implementation took place over two weeks, consisting of four meetings, each approximately 90 minutes long. The module was integrated into the school's regular mathematics lessons, aligning with the existing curriculum. During the implementation, the teacher acted as a facilitator, guiding students in using the e-comic, organizing group discussions, and encouraging active participation in exploring the storyline and reasoning patterns presented in the module. The e-comic was incorporated into every stage of the learning process, from introducing learning objectives and problem contexts to guiding students in identifying data, claims, and warrants within the comic panels and facilitating discussions to reconstruct and justify mathematical arguments. At the end of the learning sessions, both teachers and students completed response questionnaires to evaluate the practicality, clarity, and motivational aspects of the developed module, which served as the basis for assessing its effectiveness in supporting students' mathematical argumentation skills.

The Evaluation Stage was the final phase of the ADDIE model, involving the revision of the developed module based on feedback collected from validation

questionnaires to ensure its suitability for classroom implementation. This study was conducted at one of the public junior high schools in Jombang, East Java, Indonesia, involving two teachers and twenty-five students as participants. The research instruments used included validation forms to assess the quality of the e-comic-based module, teacher response questionnaires to evaluate its practicality, student response questionnaires to assess the module from the learners' perspective, and a mathematical argumentation skills test to measure students' progress after using the e-comic module. The argumentation skills assessment consisted of a pre-test administered prior to using the module and a post-test conducted afterward. The product trial included module validation, module implementation, and product revision.

Instrument

The research instruments consisted of expert validation sheets, teacher and student response questionnaires, and a mathematical argumentation skills test developed based on the Toulmin argumentation framework. Each instrument was developed through a systematic process that included design, expert validation, limited trials, and revision to ensure its validity and reliability.

The expert validation sheets were used to assess the content feasibility, design quality, and pedagogical appropriateness of the developed e-comic learning media. The validation was carried out by three experts with expertise in mathematics education and instructional media development. The evaluation employed a 5-point Likert scale ranging from very invalid (1) to very valid (5). The aspects evaluated included: alignment of content with basic competencies, accuracy of mathematical concepts, clarity of material presentation, linguistic quality, and visual and design aspects.

Teacher and student response questionnaires, questionnaires were designed to obtain feedback on the practicality and attractiveness of the e-comic learning media. The development of the questionnaires began with the formulation of items based on theoretical indicators of practicality and learning motivation in digital learning contexts, followed by expert validation and limited pilot testing.

The teacher questionnaire consisted of 12 statements covering indicators such as ease of use, alignment with curriculum materials, and the potential for classroom implementation. The student questionnaire consisted of 15 statements that assessed aspects such as visual appeal, clarity of instructions, engagement in learning, and the motivation generated by the media. A 5-point Likert scale was used for responses, ranging from "strongly disagree" (1) to "strongly agree" (5).

The mathematical argumentation skills test was developed to measure students' ability to construct and support mathematical arguments based on Toulmin's argumentation model, which includes six main elements: claim, data, warrant, backing, qualifier, and rebuttal. The test development process consisted of: determining the indicators of mathematical argumentation skills, constructing open-ended test items, expert validation by mathematics education specialists, and conducting a limited pilot test with a small group of students.

The indicators measured in this study included six aspects: claim, which refers to the ability to state a conclusion or solution; cata, which involves the ability to present relevant facts or information; warrant, which represents the ability to explain the logical connection between data and claim; backing, which indicates the ability to provide theoretical or conceptual support; qualifier, which reflects the ability to express the degree

of certainty or conditions of the claim; and rebuttal, which denotes the ability to respond to or anticipate alternative arguments. The scoring system employed a criterion-referenced rubric with a score range of 0–4 for each element, as follows: 0 = not demonstrated, 1 = very poor, 2 = fair, 3 = good, and 4 = excellent. The maximum total score for a complete argument was 24 points.

Data Analysis

The data analysis consisted of three aspects: validity, practicality, and effectiveness. The validity of the module was assessed based on the evaluations of two validators. The criteria for module validity are categorized as follows: a score between 80 and 100 is considered very valid, 60 to 80 is valid, 40 to 60 is fairly valid, 20 to 40 is less valid, and 0 to 20 is not valid (Sugiyono, 2011).

Practicality was assessed using questionnaires from both teachers and students. The criteria for practicality in the e-comic-based teaching module are categorized based on the percentage score (NA), where a score between 80 and 100 indicates very practical, 60 to 80 indicates practical, 40 to 60 indicates fairly practical, 20 to 40 indicates less practical, and 0 to 20 indicates not practical (Sugiyono, 2011).

The effectiveness of the module was determined by analyzing the improvement in test results, specifically the change in scores between the pre-test and post-test, based on students' achievement of argumentation indicators. The pre-test and post-test scores were categorized into five achievement levels, as defined by Suharsimi (2013), namely Very High (85–100), High (70–84), Medium (55–69), Low (40–54), and Very Low (0–39). Data were analyzed using a paired sample t-test and normalized gain (N-gain). Prior to the t-test, normality testing was conducted. The N-gain was used to determine the significance of improvement. The classification of the average N-gain scores is determined as follows: an average gain score (g) of 0.7 or higher is categorized as high, a score between 0.3 and 0.7 is considered medium, and a score of less than 0.3 is classified as low (Hake & Reece, 1999).

▪ RESULT AND DISSCUSSION

Analysis Stage

At the initial stage, the researcher collected data related to learning problems in schools. This activity aimed to obtain information and an overview of the teaching and learning process in the classroom. The analysis revealed that the teaching and learning process still relied on conventional media such as textbooks, with no instructional media applied that matched the students' characteristics. As a result, students were less engaged and often felt bored during mathematics lessons. Based on these findings, a teaching module based on e-comics was developed to improve students' mathematical argumentation skills, as this medium aligns well with students' characteristics.

Design Stage

After obtaining information from the analysis stage that students required supportive learning media, the following steps were carried out:

a. Designing an e-comic-based teaching module of the SPLDV topic.
b. Developing the storyline of the material, including dialogues to be presented in the e-comic.

c. Preparing research instruments to test the validity, practicality, and effectiveness of the e-comic-based teaching module.

The results of the e-comic-based teaching module design are shown in the following figures:

Figure 2. E-comic illustrating data

Figure 3. E-comic illustrating claims

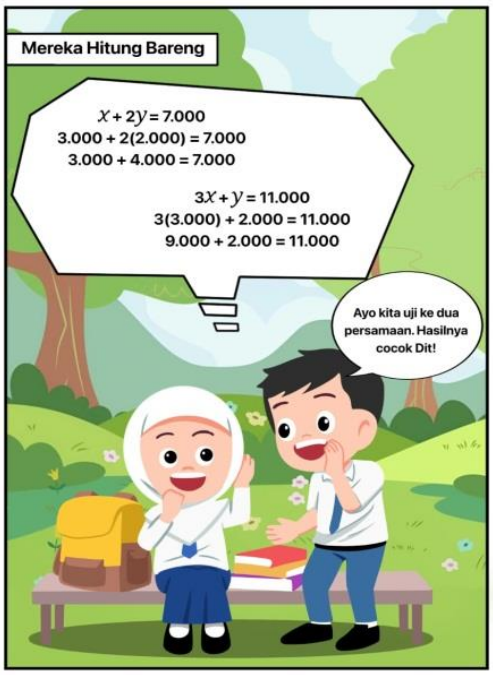

Figure 4. E-comic illustrating warrants

The presented e-comic panels demonstrate how visual, narrative, and dialogic elements work together to facilitate students' understanding of mathematical argumentation, particularly in constructing claims, data, and warrants as defined by Toulmin's model. In Figure 2, the dialogue between Dita and Pak Doni ("Pak, aku beli 1 apel dan 2 jeruk...") establishes the data of the problem, numerical information

representing quantities and prices. The narrative context (Di depan toko buah Pak Doni) situates the problem in a real-life scenario, helping students connect mathematical expressions with daily experiences. This contextualization serves as an initial stimulus for identifying data, enabling students to recognize the mathematical relationships embedded in everyday dialogue.

Figure 3 illustrates the claim component, where students (Budi and Dita) formulate a mathematical conclusion based on observed patterns: "Harga 1 buah apel Rp3.000 dan 1 buah jeruk Rp2.000." This dialogue models the process of formulating a claim, a statement derived from reasoning about available data. The teacher's response ("Betul sekali! Kalian hebat!") reinforces the validation process in argumentation, functioning as social confirmation of the claim's acceptability within the learning discourse.

Figure 4 explicitly presents the warrant, connecting data and claim through mathematical reasoning. The visual representation of equations (e.g., $x + 2y = 7{,}000$ and $3x + y = 11{,}000$) demonstrates how students justify their claims using formal symbolic language. The supporting dialogue ("Ayo kita uji ke dua persamaan. Hasilnya cocok, Dit!") models reasoning validation, showing that the argument holds when tested against both equations. This form of warrant-making encourages students to recognize the importance of logical consistency and verification in mathematical argumentation.

From a visual perspective, the sequential structure of panels provides a clear argumentative progression, from the problem context (data) to the conjecture (claim), and finally to the reasoning (warrant). The expressive facial cues and interactive body language of characters further engage students emotionally, promoting deeper cognitive involvement in following and reconstructing the logic of the argument. Moreover, the e-comic's narrative flow implicitly encourages the development of rebuttal skills. By presenting relatable dialogue and open-ended problem contexts, students are invited to question whether the identified prices (the claim) are the only possible solution, stimulating critical reflection and alternative reasoning, even if this is not explicitly shown in the comic panels. In summary, the e-comic's integrated use of dialogue, narrative context, and visual sequencing effectively scaffolds students' understanding of the components of mathematical argumentation. It not only provides an accessible representation of abstract reasoning but also models how logical relationships between data, claim, and warrant can be constructed and communicated within meaningful everyday contexts.

Development Stage

The next stage was to produce a valid e-comic-based teaching module. The validity of the module was evaluated by experts based on content, material, and language feasibility. The validation was conducted by two validators, consisting of a mathematics education lecturer and a mathematics teacher. The validation results of the e-comic-based teaching module indicate that Validator 1 achieved a total score of 48, corresponding to a validation percentage of 92.30%, which is categorized as highly valid. Validator 2 provided a total score of 50, with a validation percentage of 96.15%, also categorized as highly valid. Based on these expert assessments, the average validation percentage reached 94.23%, which indicates that the developed e-comic-based teaching module has met the required standards in terms of content, design, and language quality. The high scores in linguistic and content relevance aspects suggest that the narrative and dialogues

were designed to be clear, communicative, and aligned with students' cognitive levels, effectively facilitating argumentative thinking in accordance with Toulmin's model.

The visual representation of arguments through dialogues and contextual storylines helped students grasp the logical connections between data, claims, and warrants in solving mathematical problems. Meanwhile, the slightly lower scores in design aspects, such as color balance, panel flow, and text readability, highlight the need for minor visual refinements to enhance clarity and focus in argument presentation. Overall, these findings highlight the e-comic's strong conceptual potential to foster mathematical argumentation skills. However, technical improvements in visual design and narrative transitions are still required to optimize students' learning experiences.

Implementation Stage

In the implementation stage, the validated module was tested for practicality and effectiveness. The practicality test involved teachers and students. Teachers evaluated the ease of use, clarity of instructions, and usefulness of the module. The results are shown in Tables 1 and 2.

Table 1. Teachers' practicality assessment

No	Assessment Aspect	Teacher 1	Teacher 2
1	The e-comic-based teaching module is easy to use, requiring no special training or prior knowledge.	4	4
2	The e-comic-based teaching module can be used according to the allocated learning time.	4	4
3	The language in the e-comic-based teaching module matches the students' level of ability.	4	4
4	The layout and design of the e-comic module facilitate its use.	4	4
5	The e-comic module is easily accessible through digital devices.	4	3
6	The material in the e-comic module is easy for students to follow.	3	4
7	The e-comic module is easy to use.	3	4
8	Illustrations in the e-comic-based module help to enhance understanding of the material.	3	4
9	Activities in the e-comic module are practical to implement in class.	3	4
10	The e-comic-based teaching module can be reused in subsequent lessons.	4	4
11	The e-comic-based teaching module meets students' learning needs.	4	4
12	The e-comic-based teaching module helps teachers achieve learning objectives.	4	3
Teacher Response Percentage		92%	96%
Average Teacher Response Percentage		94%	
Teacher Response Criteria		Highly Practical	

The teacher response results presented in Table 1, with an average practicality percentage of 94% (categorized as highly practical), indicate that the e-comic-based

teaching module is well-suited for classroom implementation. Teachers perceived the module as easy to use, time-efficient, and compatible with students' language proficiency, which suggests that the instructional design effectively integrates pedagogical clarity with technological accessibility. The high ratings for usability and alignment with learning objectives indicate that the e-comic effectively supports teachers in managing instruction while maintaining students' engagement through its visual and narrative elements. However, slightly lower scores on accessibility and illustration clarity imply that technical refinements, such as optimizing image resolution or device compatibility, could further enhance classroom practicality. Overall, these findings demonstrate that the e-comic module not only simplifies the teaching process but also provides a flexible and motivating tool for fostering mathematical argumentation within a digital learning environment.

Table 2. Students' practicality assessment

No	Assessment Aspect	Score
1	The e-comic teaching module is easy to use, requiring minimal assistance from the teacher.	83
2	The language used in the e-comic teaching module is easy to understand.	80
3	Pictures and illustrations in the e-comic teaching module help in understanding the SPLDV material.	81
4	The instructions and steps for solving problems are clear.	80
5	The storyline in the e-comic teaching module is engaging and motivating for learning.	83
6	The SPLDV material is presented in a systematic and coherent manner.	79
7	The e-comic teaching module can be used for independent learning at home.	82
9	The appearance of the e-comic teaching module (color, font, layout) is attractive and comfortable to read.	81
10	The e-comic teaching module makes it easier to understand the SPLDV concept.	84
11	The e-comic teaching module helps sharpen logical thinking skills.	83
12	The e-comic teaching module can be easily accessed through devices owned by students.	83
13	Using the e-comic teaching module makes learning more enjoyable.	82
14	The e-comic teaching module provides practice questions relevant to daily life.	82
15	The e-comic teaching module helps increase confidence in solving SPLDV problems.	83
Total Student Response Score		1.230
Maximum Score		1.500
Student Response Percentage		82%
Criteria		Highly Practical

The results of the student response questionnaire, presented in Table 2, show a practicality percentage of 82%, categorized as "highly practical," indicating that the e-comic-based teaching module was well received by students and effectively supported their learning process. High scores in aspects such as ease of use, engaging storyline, and the relevance of illustrations to the material suggest that the e-comic successfully created

an enjoyable and meaningful learning experience. The contextual narrative and argument-driven dialogues helped students understand Systems of Linear Equations in Two Variables (SPLDV) more concretely and logically. Additionally, the systematic presentation of material and the visually appealing design increased students' confidence and motivation to learn independently at home. However, the slightly lower score on sequencing content implies a need for minor improvements in concept flow or the inclusion of additional exercises to strengthen conceptual coherence. Overall, these results highlight that the e-comic serves not only as an attractive visual medium but also as an effective tool for fostering cognitive engagement, learning motivation, and logical reasoning skills in mathematics education.

Based on Table 1, it is evident that the results of the practicality questionnaire for the e-comic-based teaching module, as reported by teachers, yielded an average score of 94%, indicating a highly practical category. Teachers stated that the e-comic-based teaching module was easy to use in the learning process, did not require complex additional devices, and that its presentation flow helped teachers enhance students' mathematical argumentation skills in the SPLDV material. Meanwhile, Table 2 shows that the results of the practicality questionnaire, as assessed by students, achieved an average score of 82%, which also falls within the highly practical category. Students assessed that the e-comic-based teaching module was attractive, easy to use, and motivated them to learn mathematics more effectively.

The data on students' mathematical argumentation skills were collected using a mathematical argumentation skills test instrument. This test instrument was validated by a mathematics education lecturer (media expert) and a teacher from a public junior high school (learning expert). The validation results are as follows: the media expert assigned a total score of 39, with a validity percentage of 97.5%, which is categorized as very valid. The learning expert assigned a total score of 38, with a validity percentage of 95%, which is also categorized as very valid. The average validity percentage of the mathematical argumentation skills test instrument was 96.25%, which falls into the very valid category. Additionally, a reliability test was conducted using Cohen's Kappa to assess the level of agreement between raters (inter-rater reliability). The analysis results showed a Cohen's Kappa value of 0.86, which falls into the "almost perfect agreement" category according to the criteria proposed by Landis & Koch (1977). This indicates that the mathematical argumentation skills test instrument has a very high level of rating consistency and is therefore reliable for use in research.

The effectiveness aspect of the e-comic-based teaching module was measured by comparing students' mathematical argumentation skills before and after using the module. The data were obtained through a pre-test and a post-test. The normality test in this study employed the Shapiro-Wilk test, as the number of research subjects was fewer than 50 students. The results of the normality test for pre-test and post-test data are presented in Table 3.

Table 3. Results of normality test for pre-test and post-test

E-comic-based Teaching Module	Shapiro-Wilk		
	Statistic	**df**	**Sig.**
Students' mathematical argumentation ability at one of the public junior high schools in Jombang, East Java, Indonesia			

Before (Pre-test)	.932	25	.099
After (Post-test)	.926	25	.069

Lilliefors Significance Correction

Based on Table 3, it can be seen that the significance value (Sig.) for the pre-test data is 0.099, and for the post-test data, it is 0.069. Both values are greater than 0.05. Thus, it can be concluded that both pre-test and post-test data are normally distributed.

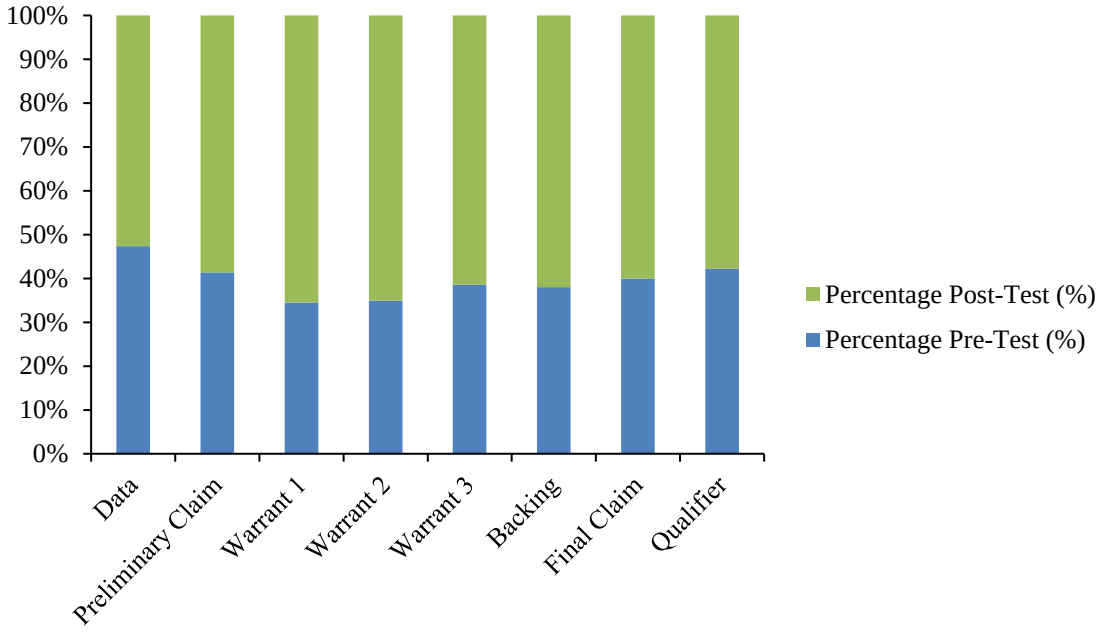

Figure 5. Stacked bar chart of pre-test and post-test

The 100% stacked bar chart in Figure 5 shows changes in the proportion of achievement for each argumentation component from pre-test to post-test. The Data component increased from 90% to 100%, and the Preliminary Claim increased from 64% to 90.8%, indicating better information identification and stronger initial claims. Significant gains were observed in Warrant 1 (50.6%–96%) and Warrant 2 (46.6%–86.7%), indicating improved logical reasoning in linking data and claims. Backing rose from 54% to 88%, Final Claim from 62% to 93.2%, and Qualifier from 60% to 82%, reflecting enhanced justification, conclusion-making, and conditional reasoning. Overall, the results indicate that the e-comic-based module strengthened not only basic argument components but also higher-level reasoning, justification, and coherence, enabling students to transition from simple to more structured and logical argumentation. The scatter plot, as shown in Figure 6, illustrates the relationship between the pre-test scores (vertical axis) and post-test scores (horizontal axis) of 25 students.

Figures 7 and 8 show one student's written argument in the warrant component during the pre-test and post-test. The pre-test result (Figure 7) shows that although the student correctly applied the elimination method and obtained the result (x = 7,000), the absence of explanations or reasoning for each step indicates difficulty in constructing the warrant component of mathematical argumentation. This difficulty aligns with findings

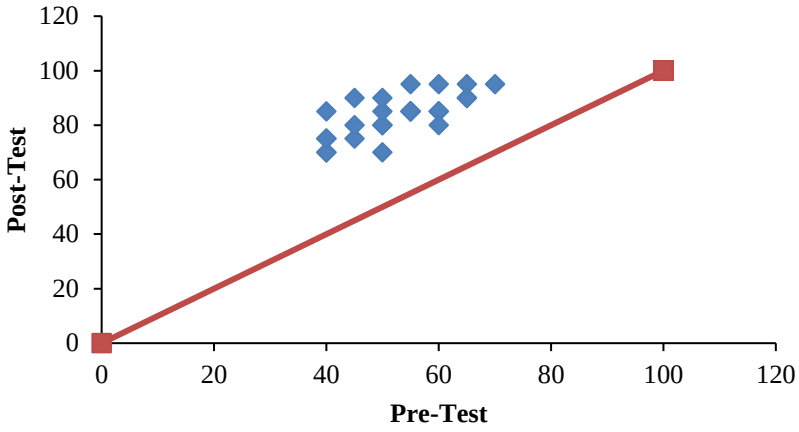

Figure 6. Scatter plot of pre-test and post-test scores

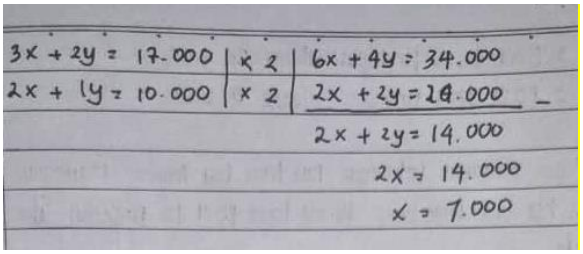

Figure 7. The student's written argument in the warrant component during the pre-test

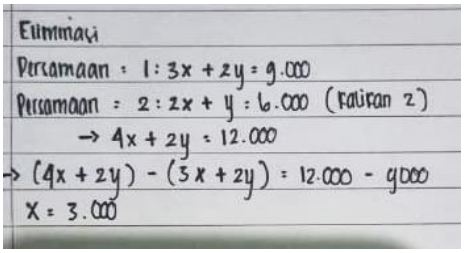

Figure 8. Student's written argument in the warrant component during the post-test

from international studies, which show that students often focus on procedural accuracy rather than conceptual justification. According to Johansson & Sumpter (2025), students tend to use procedure-based warrants, explaining how steps are performed, rather than concept-based warrants that clarify why the steps are valid. Similarly, Lehmann & Friend (2025) highlight that mathematics instruction rarely provides explicit guidance for developing complete arguments (claim, data, warrant), which causes students to struggle in linking their reasoning to their solutions. In the post-test (Figure 8), however, the students' more precise and more logical presentation after using the e-comic suggests improved conceptual understanding and the ability to articulate the warrant explicitly, demonstrating the positive impact of structured scaffolding through the e-comic medium.

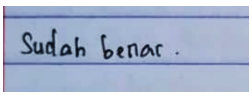

Figure 9. The student's written argument in the qualifier component during the pre-test

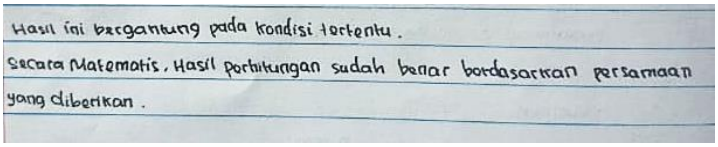

Figure 10. The student's written argument in the qualifier component during th post-test

The pre-test result (Figure 9) shows that the qualifier statement "It is correct" reflects the student's belief that the result was absolutely true without considering any context or specific conditions. This indicates that the student had difficulty constructing a qualifier because they had not yet understood that mathematical truth is contextual and depends on underlying assumptions or conditions. This difficulty aligns with Reuter (2023), who explained that students often fail to recognize the limits of applying mathematical concepts because instruction tends to emphasize procedures rather than reflection on the conditions that affect the validity of results. Furthermore, Bredow & Knipping (2025) emphasized that students' ability to use qualifiers is strongly influenced by the teacher's role in facilitating argumentative discussions that challenge students to evaluate the validity and accuracy of claims based on specific mathematical contexts. In the post-test (Figure 10), the qualifier statement became more reflective and conditional: "This result depends on certain conditions. Mathematically, the calculation is correct based on the given equations," indicating that after using the e-comic, the student began to understand that the correctness of a mathematical result depends on the conditions and mathematical principles applied, thereby improving the contextual and critical quality of their argumentation

Since the normality test indicated that the data were normally distributed, the next step was to conduct a paired-sample t-test. This test aimed to evaluate if there was a meaningful difference between students' average scores in mathematical argumentation skills before and after the implementation of the e-comic-based teaching module. The results of the paired sample t-test are presented in Table 4.

Table 4. Paired sample t-test results

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	df	Sig. (2-tailed)
Pair 1	Pre-test – Post-test	31.20000	6.65833	1.33167	33.94842	28.45158	23.429	24	.000

According to Table 4, the significance value (Sig. 2-tailed) is 0.000, which is below the threshold of 0.05, indicating a statistically significant difference between the pre-test and post-test scores. Although definitive causal claims cannot be made in the absence of a control group, these findings provide preliminary evidence of the module's potential to support the development of students' mathematical argumentation skills. Paired-samples Cohen's d (dz) results are shown below:

$$d_z = \frac{\text{Mean difference (Pre } - \text{ Post)}}{\text{Std. Deviation of paired differences}} = \frac{31.20}{6.65833} \approx 4.69$$

The effect size (Cohen's d = 4.69) indicates an extremely large practical effect, meaning that the post-test scores improved substantially after the implementation of the e-comic-based teaching module.

Besides the t-test, the module's effectiveness was also measured using the N-Gain score, which averaged 0.66. Based on Hake's classification, this score falls within the

moderate improvement range ($0.3 < g < 0.7$). This suggests that the e-comic-based module makes a substantial contribution to the development of students' argumentation skills in mathematics.

Classroom observations revealed that students still faced challenges in fully grasping the concepts of systems of linear equations in two variables (SPLDV), especially when it came to formulating mathematical arguments. Meanwhile, teachers predominantly relied on traditional teaching materials such as textbooks, which are mainly text-based and tend to be less engaging. This aligns with prior research indicating that instruction relying heavily on text reduces student engagement in mathematical thinking (Tristanti & Nusantara, 2021b).

Therefore, there is a clear demand for innovative instructional media that combine mathematical concepts with appealing visuals. One promising option is an e-comic-based teaching module, which can present SPLDV problems through relatable storylines and simultaneously support the enhancement of students' mathematical argumentation skills (Sepeng, 2013; Sepriyanti & Tapia, 2018; Widodo et al., 2018).

In the design stage, the e-comic-based teaching module framework was developed by relating real-life situations to SPLDV problems. The storyline was carefully constructed to enable students to understand SPLDV concepts through a contextual and engaging narrative (Chu & Toh, 2020; Toh et al., 2017). During this phase, instruments were also created to assess the module's validity, usability, and effectiveness. These tools included: (1) validation sheets for evaluating content, structure, and language; (2) questionnaires for teachers to provide feedback on the module's practicality; (3) questionnaires for students to assess both usability and engagement; and (4) mathematical argumentation tests to measure students' progress following use of the e-comic module.

The design of the e-comic, which integrates visual, narrative, and mathematical dialogue elements, has been proven to enhance students' mathematical argumentation skills. The findings of this study show that presenting problem contexts through illustrations and character dialogues helps students identify data components, formulate claims, and construct warrants logically according to Toulmin's framework. This result aligns with Mayer's Cognitive Theory of Multimedia Learning, which explains that the integration of text and images strengthens dual coding processes in the brain, thereby improving conceptual understanding.

Yulaichah et al. (2024) also support these findings, showing that the use of e-comics based on Realistic Mathematics Education (RME) can enhance students' critical and creative thinking skills. The narrative and visual aspects of e-comics make reasoning processes more contextual, helping students construct evidence-based mathematical arguments. Similarly, Nugraha & Samsudin (2024) found that using e-comics in mathematics instruction contributes to the improvement of students' mathematical disposition, including positive attitudes, perseverance, and confidence in logical thinking. Such a positive disposition is an essential foundation for students to express and defend their mathematical arguments confidently in classroom discussions.

Furthermore, Farhan et al. (2024) revealed that contextual e-comics adapted to students' cultural backgrounds significantly enhance learning motivation and mathematics achievement. This increase in motivation and engagement supports Keller's ARCS Motivation Model, which emphasizes that the attention and relevance aspects of

instructional media play crucial roles in shaping students' cognitive readiness to engage in deeper and more argumentative thinking.

Therefore, the design of e-comics that combine realistic contexts, narrative flow, and argumentative dialogue not only strengthens conceptual understanding but also facilitates reflective and critical thinking processes. Through activities of reading, analyzing, and verifying character arguments within the e-comic, students learn to construct logical and evidence-based mathematical arguments. These results are consistent with recent international studies that confirm the effectiveness of interactive visual media, such as e-comics, in enhancing higher-order thinking skills, including mathematical argumentation.

During the development phase, a draft version of the e-comic teaching module was created, incorporating character illustrations, dialogues, and contextual problems seamlessly integrated into the storyline. This draft was then reviewed by a panel consisting of a mathematics education lecturer and two mathematics teachers to assess the module's feasibility in terms of design, content, and language. The evaluation used a Likert-scale instrument, a standard method in development research for assessing educational materials (Plomp, 2013; Sugiyono, 2011). The validation results indicated that the e-comic module achieved an average score of 94%, indicating high validity and confirming its readiness for further implementation (Badeo & Koc, 2022; Fitriani & Ronny, 2025).

During the implementation phase, the e-comic-based teaching module was trialed to evaluate its practicality and effectiveness. Following its use, both teachers and students completed response questionnaires, and students' mathematical argumentation skills were measured through a dedicated test. Observations revealed increased student enthusiasm when using the e-comic module, as the storyline and characters resonated with their everyday experiences. This supports the findings of Lin & Lin (2016), who found that comics enhance student engagement and motivation, as well as those of Khotimah & Hidayat (2022), who emphasized that digital comics provide a more practical and engaging learning environment. Practicality data were collected via questionnaires from both teachers and students, with teacher feedback averaging 94%, indicating the module was highly practical. Teachers noted that the e-comic-based module was easy to use in teaching, did not require complex additional devices, and its presentation flow helped them foster students' mathematical argumentation skills in learning SPLDV. Meanwhile, student responses showed an average score of 82%, also categorized as very practical. Students considered the module engaging, easy to use, and motivating in learning mathematics. Thus, the e-comic-based teaching module can be concluded to be practical, as its storyline is clear, easy to apply, and promotes active student involvement in the learning process.

In the evaluation stage, the effectiveness of the e-comic-based module was tested. Effectiveness was examined by administering pre-tests and post-tests on students' mathematical argumentation skills. Before conducting the t-test, a normality test was carried out on the pre-test and post-test results to ensure that the data were normally distributed, a prerequisite for parametric tests. The Shapiro-Wilk test using SPSS confirmed that both datasets were normally distributed. Therefore, a paired sample t-test was conducted, showing a significance value (Sig. 2-tailed) of $0.000 < 0.05$, indicating a significant difference between the pre-test and post-test results. The e-comic-based

teaching module has the potential to enhance students' mathematical argumentation skills.

Its effectiveness was further evaluated using the N-Gain score, which averaged 0.66. Based on Hake's criteria, this score is categorized as moderate improvement ($0.3 < g < 0.7$), indicating that the module made a significant contribution to students' progress in mathematical argumentation. These results align with those of Lin et al. (2015), who highlighted that comics can enhance student engagement and promote critical thinking. Additionally, Tristanti and Nusantara (2022), as well as Tristanti et al. (2024a, 2024b), have underscored that interactive and contextual learning tools effectively foster mathematical argumentation skills. International research also supports these outcomes; for instance, Bina et al. (2024) found that Webtoon-based digital comics enhanced students' mathematical communication, while Mamolo (2019) developed Digital Interactive Math Comics that increased student motivation and learning achievements. Collectively, both local and global studies emphasize the value of incorporating visual technology-based innovations in mathematics education.

The final phase of the ADDIE model involved revising the developed module based on feedback obtained from expert validation and user response questionnaires. This step ensured that the e-comic-based teaching module was feasible and ready for classroom implementation. The study was conducted at one of the public junior high schools in Jombang, East Java, Indonesia, involving two mathematics teachers and twenty-five students as participants. The relatively small sample size was determined by the exploratory and developmental nature of the research, which aimed to evaluate the feasibility, practicality, and initial effectiveness of the e-comic module rather than to generalize the findings to a wider population. The limited number of participants allowed for in-depth observation and detailed qualitative analysis of students' learning interactions and argumentation processes. Nevertheless, this small sample size is recognized as a primary limitation of the study, as it restricts the generalizability of the results. Future studies with larger and more diverse samples are recommended to strengthen the external validity and confirm the broader applicability of the developed e-comic module.

This study employed only a pre-test and post-test design without the inclusion of a control or comparison group. Therefore, the observed improvement in students' mathematical argumentation skills cannot be attributed conclusively to the use of the e-comic-based module alone. The findings should be interpreted as preliminary evidence, and further research with a more rigorous experimental design is required to strengthen these conclusions.

▪ CONCLUSION

The results indicate that the e-comic-based teaching module developed in this study is highly valid, practical, and effective for mathematics instruction, particularly on the topic of systems of linear equations in two variables (SPLDV). Validation scores averaged 94%, while ratings of practicality from teachers (94%) and students (82%) confirm the module's strong usability. The paired sample t-test revealed a significant difference between pre-test and post-test scores, with an N-Gain value of 0.66, categorized as moderate improvement. These findings suggest that the e-comic-based

module has the potential to enhance students' ability to construct, justify, and evaluate mathematical arguments.

This study deepens the theoretical understanding of how visual and narrative media influence mathematical argumentation. By integrating visual storytelling, contextual problems, and character dialogue, e-comics provide multimodal scaffolding that bridges intuitive and formal reasoning. This mechanism clarifies how students internalize argumentative structures and why visual narrative formats support logical justification in mathematics learning.

Practically, the findings highlight the value of incorporating e-comic-based materials into mathematics instruction to improve engagement and reasoning quality. Teachers can adapt this model to other mathematical topics, while educational developers can design digital learning tools that blend visualization, interactivity, and narrative coherence. Such practices foster a more human-centered, creative, and meaningful learning experience for students.

Looking ahead, this research opens new directions for the development of adaptive, AI-assisted e-comic learning systems that can personalize feedback on students' argumentative reasoning. Expanding this approach to diverse mathematical domains and broader student populations could yield deeper insights into how visual media can shape the evolution of mathematical thinking and discourse.

Synthesizing these findings, the study contributes both practical and theoretical insights into the design of visual-based learning media for mathematics education. Looking ahead, future research could integrate interactive or adaptive e-comics, expand to broader mathematical topics, and explore long-term impacts on students' reasoning trajectories. Such developments will advance a more dynamic, human-centered, and visually enriched paradigm of mathematical learning.

This study extends theoretical understanding of how narrative-based visual media, such as e-comics, facilitate the learning of mathematical argumentation through multimodal scaffolding mechanisms that integrate visual, textual, and contextual representations to bridge intuitive and formal reasoning. Practically, yet grounded in theory, the findings indicate that the use of e-comics in mathematics learning not only enhances student engagement but also serves as a pedagogical model informed by multimodal cognitive theory, which can be adapted to foster argumentative and higher-order thinking skills across various mathematical topics.

Given the limited sample size and single-site implementation, future studies are encouraged to involve larger and more diverse populations across different school contexts to enhance the generalizability of the findings. Further research could also employ mixed-method or longitudinal designs to examine the sustained impact of e-comic-based instruction on students' mathematical argumentation development over time. In addition, exploring the integration of interactive or adaptive digital features within the e-comic platform may provide deeper insights into how technological affordances can optimize students' engagement, reasoning, and argumentation processes in mathematics learning.

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