Designing and evaluating SIMaV: A conceptual macro-visualization system to enhance students' mathematical abstraction ability

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Abstract

This study aims to develop a design SIMaV conceptual macro-visualization system for linear systems with two variables at the junior high school level and to examine its feasibility and effectiveness in improving students' mathematical abstraction ability. This research is grounded in the limitations of existing instructional media, which tend to present mathematical concepts through partial or fragmented visualizations that hinder students' holistic understanding and abstraction processes. To address this gap, SIMaV introduces a novel macro-visualization approach that presents mathematical relationships dynamically and comprehensively, making a new contribution to visualization-based learning in mathematics education. The research method employed was Research and Development (R&D) using the ADDIE model, comprising the analysis, design, development, implementation, and evaluation stages. The research subjects included content experts, media experts, and eighth-grade students. The validation results from content and media experts indicated that the developed medium falls into the "feasible" to "highly feasible" category. Students' responses to the medium were very positive, as indicated by an average questionnaire score of 3.5 out of 4. In addition, the improvement in students' abstraction ability was shown by an N-Gain score of 0.63, which is categorized as "moderate." This medium has proven to help students better understand the concept of linear systems with two variables through its interactive features. Therefore, SIMaV media is suitable for use as an innovation in conceptual macro-visualization systems, particularly for improving students' mathematical abstraction skills.

Keywords:
Abstraction, Conceptual instruction, Instructional media design, Mathematics learning media, SIMaV

1. INTRODUCTION

Mathematics learning plays a strategic role in developing students' higher-order thinking skills, particularly reasoning, problem-solving, and the ability to abstract real-world

situations. However, numerous studies indicate that mathematics instruction at the secondary school level is still predominantly characterized by procedural and symbolic approaches. As a result Rodríguez-Nieto and Font Moll (2025), students often experience difficulties in achieving deep conceptual understanding, especially in the topic of System of Linear Equations in Two Variables. Linear systems with two variables is an essential topic that requires students to connect real-world contexts with mathematical representations in the form of symbols, graphs, and equations. Santoso et al. (2019) state that students' difficulties in learning linear systems with two variables generally arise at the stage of modeling contextual problems into algebraic forms and interpreting the meaning of solutions conceptually. This condition indicates that learning linear systems with two variables requires not only procedural mastery but also strong mathematical abstraction ability.

Mathematical abstraction ability is a higher-order cognitive skill that enables students to transform concrete objects or contextual situations into formal mathematical structures and to meaningfully connect various mathematical representations (Vermehren et al., 2025). Recent studies indicate that low levels of mathematical abstraction ability have a direct impact on students' weak conceptual understanding, representation skills, and mathematical communication (Özdemir et al., 2021). Therefore, Zulfakri et al. (2019) stated that strengthening mathematical abstraction ability has become one of the primary objectives of modern mathematics education, particularly in algebraic topics that require symbolic reasoning and conceptual generalization.

One instructional approach considered effective in supporting the abstraction process is the use of visualization in mathematics learning (Tang & Pereira, 2025). Andriatna et al. (2025) state that visualization serves as a cognitive bridge between concrete objects and abstract concepts, enabling students to construct more stable and meaningful conceptual structures. Empirical studies show that visualization-based learning environments facilitate students' ability to generalize patterns, connect representations, and reason about mathematical relationships. Meta-analyses and systematic reviews conducted over the past five years further confirm that visualization-based mathematics instruction significantly improves students' conceptual understanding, mathematical reasoning, and overall learning outcomes compared to conventional instructional approaches (Zheng et al., 2025). In the Indonesian context, several studies have reported that conceptual macro-visualization system including animated videos, interactive multimedia, and technology-assisted instructional tools, are valid, practical, and effective for learning Systems of Linear Equations in Two Variables, and is not limited to partial or fragmented visualization, but is implemented through macro visualization (Pertiwi et al., 2021; Wanabuliandari et al., 2025). This involves three distinct aspects, namely; 1) Partial visualization refers to the presentation of mathematical concepts that displays only a single aspect or a single form of representation without explicit connections to other representations. In mathematics learning, this approach generally focuses on final outcomes or specific procedural steps. In the context of the System of Linear Equations in Two Variables, partial visualization may take the form of presenting the graphs of two straight lines on the coordinate plane without relating them to the algebraic equations, real-world problem contexts, or the meaning of the point of intersection as the solution of the system. According to multiple representation theory, students' interaction with only one type

of representation leads to limited conceptual understanding (Dinçer, 2025). Consequently, partial visualization tends to result in shallow and procedural understanding, as students do not construct conceptual connections among mathematical representations. 2) In contrast to partial visualization, fragmented visualization presents multiple mathematical representations, but they are delivered separately and are not cognitively integrated.

Although richer in terms of representational variety, the relationships among these representations are not explicitly explained. In the context of System of Linear Equations in Two Variables, fragmented visualization can be observed when students learn contextual word problems, algebraic equations, and graphical representations in different sections or learning sessions without activities that connect the three as a unified concept. Based on Cognitive Load Theory (Sweller, 2020), this condition has the potential to increase extraneous cognitive load because students must independently integrate separated pieces of information (Barbieri & Rodrigues, 2025). This increased cognitive load often hinders the formation of comprehensive conceptual understanding and leads to difficulties in the process of mathematical abstraction (Pyke et al., 2024). Conversely, macro visualization is a visualization approach that presents mathematical concepts in a holistic, integrated, and simultaneous manner by connecting multiple representations into a coherent whole (Pertiwi et al., 2021; Rohaeti et al., 2019).

In linear systems with two variables learning, macro visualization is realized through the presentation of contextual problems that are directly linked to symbolic representations in the form of algebraic equations, visual representations in the form of graphs, and conceptual representations that explain the meaning of the solution as the point of intersection and the relationships between variables. All representations are presented in an integrated manner and can be explored simultaneously (Robins, 2022). This approach aligns with Dual Coding Theory, which emphasizes the integration of visual and symbolic information; mathematical abstraction theory, which views abstraction as a process of pattern recognition, generalization, and integration of representations; and APOS Theory, which supports cognitive transitions from actions to processes, objects, and schemas. Through macro visualization, students not only understand procedural solutions but also construct stable and deep conceptual structures, enabling their mathematical abstraction ability to develop optimally.

Maifa et al. (2025) argue that most learning media based on conceptual macro-visualization systems developed to date still tend to emphasize partial or fragmented visualization. Partial visualization refers to the presentation of concepts in isolation, for example, displaying the graphs of two linear equations without explicitly connecting them to real-world problem contexts, the algebraic forms of the system of equations, or the meaning of the solution as the point of intersection of the two graphs. As a result, students tend to understand only certain components of the linear systems with two variables separately. In contrast, macro visualization emphasizes a holistic and integrated presentation of concepts. In the context of System of Linear Equations in Two Variables, macro visualization not only presents graphical representations of equations but also simultaneously links them with contextual representations (word problems), symbolic representations (algebraic equations), and conceptual representations (the meaning of the solution and the relationships between variables) (Zhang et al., 2025). This approach enables students to perceive the interconnections among representations as a coherent whole, thereby supporting deeper mathematical

abstraction processes. Therefore, the existing gap indicates that currently available learning media have not optimally facilitated holistic abstraction processes. Consequently, there is a need to develop instructional media that are explicitly designed to integrate multiple representations through macro visualization in order to more effectively support students' mathematical abstraction abilities.

Based on these issues, there is a need for learning media design that is not only visual in nature but also explicitly supports conceptual learning and students' mathematical abstraction processes. Therefore, this study proposes SIMaV, a conceptual macro-visualization system to facilitate macro visualization in learning System of Linear Equations in Two Variables. SIMaV systematically integrates contextual, visual, and symbolic representations, enabling students to develop deeper conceptual understanding and enhance their mathematical abstraction ability. Accordingly, this article aims to examine how the design of SIMaV functions as an effective conceptual instructional medium in improving students' mathematical abstraction ability in linear systems with two variables and to contribute to the development of visualization-based innovations in mathematics education.

2.   METHOD

This study employed a Research and Development (R&D) design with a descriptive quantitative approach combined with a quasi-experimental quantitative approach to develop, validate, and evaluate the feasibility and effectiveness of the interactive learning media SIMaV. The development process followed the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation.

The analysis stage, a needs analysis was conducted to identify students' learning difficulties and teachers' instructional needs related to the topic of Systems of Two-Variable Linear Equations. This stage involved classroom observations, interviews with mathematics teachers, student questionnaires, and document analysis of the existing curriculum and learning materials. The results of this analysis indicated that students experienced difficulties in understanding abstract mathematical concepts due to limited visualization and conceptual macro-visualization systems. These findings were used as the basis for designing the SIMaV media.

The design and development stages, the learning media was designed according to the identified needs and curriculum requirements. The developed SIMaV media was then validated by media experts and content experts using expert validation sheets. The validity of the instruments was ensured through content validity, which was examined by expert judgment. The reliability of the expert validation and student response questionnaires was measured using appropriate reliability coefficients (e.g., Cronbach's alpha), indicating that the instruments were reliable for data collection.

The implementation stage applied a quasi-experimental design with a pretest-posttest control group design. The participants consisted of eighth-grade students from a junior high school, who were divided into an experimental group and a control group. The experimental group learned using the SIMaV media, while the control group received conventional instruction. The sampling technique used was purposive sampling, based on the similarity of

students' initial mathematical abilities. A mathematics teacher was also involved to support the implementation of the learning process. To measure the effectiveness of the media, pretest and posttest instruments were administered to both groups. The test instruments were developed based on indicators of mathematical abstraction ability. Content validity was ensured through expert review, and a pilot test was conducted to examine the clarity and suitability of the test items before implementation.

The evaluation stage, data analysis was carried out using both descriptive and inferential statistics. Descriptive statistics were used to analyze expert validation scores and student response questionnaires. The effectiveness of SIMaV media was analyzed using an independent samples t-test to compare the posttest scores of the experimental and control groups, as well as a paired samples t-test to examine students' learning improvement within each group. In addition, N-Gain analysis was conducted to determine the level of improvement in students' mathematical abstraction ability after using the SIMaV.

The development model applied in this study was the ADDIE model is Analysis, Design, Development, Implementation, and Evaluation (Hidayat et al., 2023; Muhammad et al., 2025), which consists of the following stages (see Figure 1).
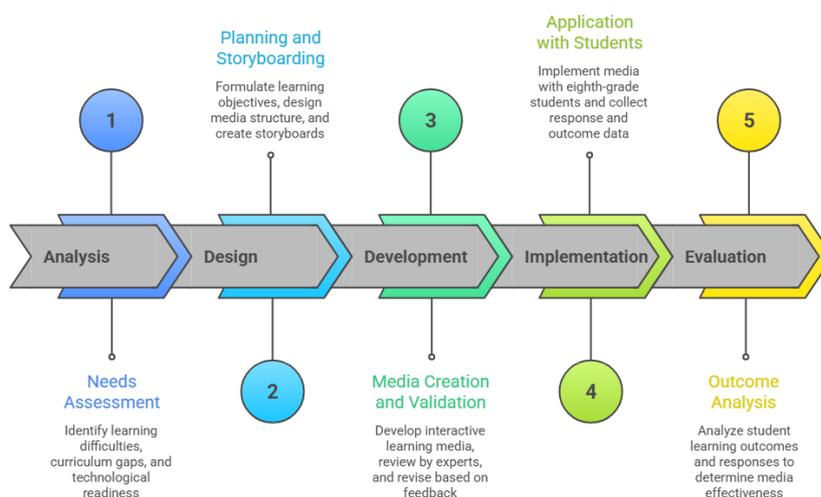
Figure 1. Research procedure based on the ADDIE model

The following is an explanation of the ADDIE flow shown in Figure 1, which includes the analysis stage was carried out to identify the difficulties experienced by students and teachers in learning Systems of Two Variable Linear Equations and to explore the potential for developing SIMaV learning media. As illustrated in Figure 1 (Stage 1: Analysis/Needs Assessment), the findings revealed that many students had difficulty understanding the concepts due to their abstract nature and the lack of adequate visualization in conventional instruction.

The curriculum and basic competency analysis indicated that the topic of Systems of Two-Variable Linear Equations is aligned with the Grade VIII junior high school curriculum, which emphasizes solving and applying these systems in real-life contexts. Furthermore, the analysis of student characteristics showed that learners tend to be more motivated and actively engaged in visual and interactive learning environments than in traditional lecture-based approaches. The specific methods used for needs analysis surveys, interviews, and document

analysis, so how the results informed the design The facilities and technology analysis also demonstrated that most schools are equipped with computers or laptops installed with Microsoft Office. Therefore, this platform was chosen because it is accessible, user-friendly, and free of charge, making it suitable for classroom implementation.

The design stage focused on planning and structuring the SIMaV instructional media by integrating interactive features such as quizzes, navigation buttons, and simulations of problem-solving steps for Systems of Two-Variable Linear Equations. The selection of these interactive features was theoretically grounded in the concept of mathematical abstraction, which emphasizes the transition from concrete representations to symbolic and conceptual understanding. Interactive elements were designed to support students in identifying patterns, generalizing relationships, and connecting multiple representations of mathematical concepts. This stage involved planning and storyboarding, formulating learning objectives, designing the media structure, and creating detailed storyboards as illustrated in Figure 1.

The learning content was mapped systematically, including definitions, general forms, and three solution methods: elimination, substitution, and graphical methods. Storyboards and media flowcharts were then developed to organize screen layouts, navigation paths, animations, and system responses to students' inputs. Navigation buttons were intentionally designed to allow students to control the learning sequence, enabling them to revisit previous materials and explore concepts at their own pace. This feature supports abstraction by encouraging reflective thinking and reinforcing conceptual connections. Quizzes and multiple-choice questions were embedded to prompt students to test their understanding of abstract relationships between variables, while immediate feedback helped students refine their reasoning and correct misconceptions. Furthermore, simulations of solution procedures were developed to visualize step-by-step problem-solving processes, particularly the transformation from verbal problems to algebraic models and graphical representations.

These simulations were intended to help students bridge concrete problem contexts with symbolic expressions and graphical forms, which is a key aspect of developing mathematical abstraction ability. To support quality assurance, media feasibility assessment instruments were also prepared for evaluation by content experts, media experts, and students, focusing on content accuracy, instructional design, interactivity, and alignment with learning objectives.

The development stage involved producing the SIMaV instructional media using macro programming based on Visual Basic for Applications (VBA) within the Microsoft Office environment. This programming environment was selected due to its compatibility with commonly used educational software and its ability to support interactive features such as automated answer checking, navigation control, and immediate feedback. The development process focused on translating the designed storyboards into a functional interactive media by implementing programmed menus, input fields, quizzes, and simulations of problem-solving steps. During this stage, interactive features such as answer validation, automatic feedback, and controlled navigation were developed to support meaningful and self-directed student learning. Visual elements, including images, diagrams, and supporting animations, as well as audio elements when necessary, were integrated to enhance conceptual clarity and student engagement.

Following the completion of the media prototype, expert validation was conducted to evaluate the quality and feasibility of the SIMaV media. The validation process involved content experts and media experts with expertise in mathematics education and instructional media development. Content experts assessed the accuracy, relevance, and alignment of the instructional material with learning objectives and indicators of mathematical abstraction ability. Media experts evaluated aspects related to visual design, interactivity, navigation, and technical performance of the macro programming. The experts provided both quantitative ratings and qualitative suggestions using structured validation sheets.

Based on the feedback received, revisions were made to improve content clarity, interface design, and functionality of the interactive features. The revised media were then deemed suitable for implementation and further evaluation. The implementation stage consisted of applying the developed SIMaV media in small-group (limited) trials and large-group (field) trials to examine students' responses and the effectiveness of the media, as illustrated in Figure 1 the implemented media with eighth-grade students and collected response data. This stage represented a small-scale field implementation in which SIMaV was integrated into the instructional process for teaching Systems of Two-Variable Linear Equations. The participants were Grade VIII students, with teachers incorporating the media into classroom instruction. Data were collected through student response questionnaires and classroom observations to evaluate student engagement, learning interest, and the ease of use of the media during the learning activities.

Finally, the evaluation stage was conducted through formative and summative evaluations, each serving a distinct purpose in assessing and refining the SIMaV instructional media. Formative evaluation was carried out continuously throughout the Analysis, Design, and Development stages. This evaluation involved expert reviews and limited try-outs, focusing on identifying weaknesses in content accuracy, interface design, interactivity, and technical functionality. Feedback obtained from content experts, media experts, and initial user trials was systematically analyzed and used to revise the media, resulting in improvements to learning materials, navigation flow, feedback mechanisms, and visual presentation before classroom implementation. In contrast, summative evaluation was conducted after the implementation stage to assess the overall effectiveness of the finalized SIMaV media. This evaluation focused on students' learning outcomes and was carried out by comparing pretest and posttest results. The data obtained from this stage were analyzed using statistical techniques, including N-Gain analysis, to measure the extent of improvement in students' mathematical abstraction ability after using the media.

The results of the summative evaluation provided evidence of the effectiveness of the SIMaV media and served as the basis for final conclusions regarding its feasibility and instructional impact. The integration of formative and summative evaluations ensured that the SIMaV media was not only systematically refined during development but also empirically tested for its effectiveness in improving students' mathematical abstraction ability.

The research subjects consisted of eighth-grade students of Junior High School, West Bandung Regency, as well as mathematics teachers. Data collection techniques in this study included interviews and preliminary observations for needs analysis, validation questionnaires completed by media experts and content experts, student response questionnaires regarding

the media, and learning outcome tests in the form of pretests and posttests. Data analysis techniques involved calculating the mean scores of validation results from experts and categorizing them qualitatively into very feasible, feasible, fairly feasible, and not feasible.

Student responses were analyzed descriptively using percentages. Furthermore, the effectiveness of the media was analyzed using gain analysis (N-Gain) by Hake (2002) to determine improvements in students' mathematical abstraction ability before and after the implementation of the SIMaV.

$$N - Gain = \frac{Posttest - Pretest}{Ideal\ Maximum\ Score\ - Pretest} \times 100\%$$

The N-Gain value based on the interpretation proposed by Hake (2002). Interpretation of N-Gain Values is used to classify the level of improvement in students' abilities into low, medium, and high categories (see Table 1), which serves as a basis for interpreting the effectiveness of the implemented learning media.

Table 1. Interpretation of N-Gain values

Score	Criteria
< 0.3	Low
0.3 – 0.7	Moderate
> 0.7	High

The score categories were determined based on the criteria proposed by Sihombing et al. (2025). These categories are used to classify the assessment results into specific levels of feasibility (see Table 2), such as very feasible, feasible, moderately feasible, and not feasible, thereby providing a clear description of the quality level and readiness of the SIMaV media for implementation in the learning process.

Table 2. Feasibility categories of SIMaV media

Mean Score Range	Criteria
0.00 – 1.00	Not Feasible
1.00 – 2.00	Fairly Feasible
2.00 – 3.00	Feasible
3.00 – 4.00	Highly Feasible

3.   RESULTS AND DISCUSSION

3.1. Results

The media development process was carried out through the five stages of the ADDIE model. The results of each stage are described as follows.

3.1.1. Analysis

Based on classroom observations, interviews with teachers and students, and an analysis of instructional documents, it was found that mathematics learning on the topic of Systems of Two-Variable Linear Equations still faces fundamental problems that affect the achievement of learning objectives. In general, students experience difficulties in understanding the relationships between two linear equations in symbolic, graphical, and contextual forms. Classroom instruction tends to be procedural, where teachers emphasize

computational steps such as substitution and elimination methods, with limited opportunities for students to explore the underlying conceptual meanings of these operations. As a result, students are able to solve problems mechanically but do not understand why and how two lines intersect at a single point as the solution of a System of Linear Equations in Two Variables. This condition indicates that students have not yet been able to connect symbolic representations, graphical representations, and real-world contexts, which are central to conceptual understanding of System of Linear Equations in Two Variables.

In addition, the analysis revealed that the learning resources used by teachers are still conventional and limited to textbooks, student worksheets, and simple PowerPoint slides that mainly present text and worked examples. These instructional materials require further development by incorporating dynamic visualizations that concretely illustrate the relationships among variables in System of Linear Equations in Two Variables. Moreover, interactive digital media, such as visualization-based applications, are rarely used, resulting in learning activities that are monotonous and teacher-centered. Existing learning resources have not integrated multimedia elements such as text, images, animations, and interactivity, which could otherwise support students in constructing understanding through visual experiences that bridge concrete situations and abstract thinking. Consequently, students tend to be passive and show low motivation, while mathematical thinking processes that should develop through visual exploration do not progress optimally. These findings indicate a strong need for the development of SIMaV media that can interactively visualize linear systems with two variables concepts, demonstrate the relationships between algebraic forms and graphs, and dynamically display changes when coefficients and constants are modified. An analysis of curriculum documents further showed that the learning outcomes for Phase D of the Merdeka Curriculum require students to understand and solve systems of two-variable linear equations and apply them in real-life contexts. The derived learning objectives include recognizing the general form of System of Linear Equations in Two Variables, determining solutions using various methods, and interpreting the meaning of solutions contextually. However, classroom observations indicate that these outcomes have not been optimally achieved. Many students focus only on obtaining final answers rather than engaging in the thinking processes that involve connections among multiple representations.

This situation suggests that learning activities have not adequately accommodated students' diverse learning styles and have not provided sufficient opportunities for students to construct abstraction through visual and interactive learning experiences. Therefore, the SIMaV design was developed to support students in achieving these learning outcomes more meaningfully by offering integrated learning experiences that combine text, graphs, animations, and real-life contexts within a single instructional medium. Furthermore, analysis of supporting resources at the school indicated that, although some limitations exist, the available facilities are generally adequate for implementing digital media. The school is equipped with projectors, laptops, and classrooms that support the use of visual media; however, internet access is not always stable, and teachers' proficiency in operating macro-based media is still limited. Consequently, SIMaV was designed to function offline, be easily operated through Microsoft Office without requiring additional devices, and feature a simple, user-friendly interface that can be readily understood by both teachers and students.

Overall, the analysis results indicate that learning linear systems with two variables requires media innovation capable of bridging the gap between abstract mathematical symbols and concrete visual representations. The SIMaV media design was developed as a solution to strengthen the connections among symbolic, graphical, and contextual representations through dynamic and interactive visualization. Thus, mathematics learning is expected not only to focus on final computational results but also to foster deep conceptual understanding, higher-order mathematical abstraction ability, and increased student motivation.

3.1.2. Design

The SIMaV media design was developed to help students understand the concept of Systems of Two-Variable Linear Equations in a more concrete and engaging manner. The media was created using Microsoft Office with macro programming, enabling the integration of text, graphs, animations, and control buttons within a single unified interface. This design allows students to directly observe how changes in coefficients and constants within the equations affect the positions of lines and their points of intersection on the coordinate plane, thereby making the concept of linear systems with two variables easier to understand. Figure 2 presents the main page display and several navigation menus of the SIMaV media, including learning instructions, learning outcomes, learning materials, evaluation, and quizzes.

Figure 2. SIMaV media home interface

On the initial page, users are directed to access the media through a login system as a form of learning management. Subsequently, the main menu presents learning features in Figure 2 such as Instructions, Learning Outcomes, Materials, Evaluation, and Quiz, which are visually designed with representative icons to enhance usability and engagement.

Figure 3. Instructional overview / quiz landing page

In the first section, the Learning Outcomes, Basic Competencies, indicators, and learning objectives are presented, with a focus on students' ability to construct mathematical

models and solve contextual problems related to systems of two-variable linear equations. In the second section in Figure 3 an interactive quiz page with an attractive and communicative design is provided, aiming to enhance students' mathematical abstraction ability and learning motivation prior to completing the evaluation. The learning materials are systematically organized, starting from definitions and the general form of the equations to their key characteristics, and are presented in colored visual panels that are clear and easy to read. In Figure 3 each concept is accompanied by supporting symbols and icons to reinforce students' understanding of abstract mathematical concepts.

Figure 4. Guided practice / worked example section

Students are guided to analyze concrete application problems accompanied by systematic solution steps, starting from mathematical modeling, followed by the elimination method, the substitution method, and concluding with drawing conclusions in Figure 4. In the final display, features such as score checking, restart, and return to the main menu are provided as feedback on learning outcomes and to reinforce the evaluation process.

The macro programming language used in the SIMaV media is specifically designed to support the development of interactive and dynamic learning features. Developers can learn this macro language through various reference books, technical documentation, and relevant online learning resources. However, understanding the theoretical concepts alone is not sufficient. Continuous practice is essential to fully comprehend the syntax structure, logical flow, command execution, and functional integration within the system. Mastering this macro programming language enables developers to control visual objects, manage user interactions, automate processes, and integrate mathematical simulations systematically. Through consistent practice and experimentation, developers can optimize SIMaV's functionality, resulting in more responsive, adaptive, and pedagogically effective learning media. In Figure 5, the visual macro code is presented as an example of the syntax structure and command implementation used in developing the SIMaV media.

Figure 5. Macro programming

The Figure 5 presents several segments of macro (VBA) code embedded in PowerPoint-based learning media to create an interactive quiz system. Each section is organized into separate procedures (Sub), such as elimination, combination, substitution, graphical method, technology, and information. Within each procedure, a message box (MsgBox) is displayed to provide a brief explanation of a particular problem-solving method. The program then evaluates the user's response using a conditional structure, typically If confirmation = vbYes Then. When the response is correct, the variable answere-good (correct answers) is incremented to record the score. After processing the response, the command Active-Presentation-SlideShowWindow-View-Next automatically directs the presentation to the next slide. Then qverall, the code demonstrates how macro programming is utilized to manage user interaction, assess responses, calculate scores, and control slide navigation. This structure supports a more interactive, systematic, and responsive learning experience within the presentation media.

3.1.3. Development

The media were developed and their validity was evaluated by ICT media experts and content experts. Revisions were made based on the suggestions provided by the validators.

Content Expert Validation

The results of the content expert validation indicate that the developed SIMaV media obtained an average score of 3.6 out of 4 (see Table 3), which falls into the "Highly Feasible" category. This assessment reflects that the instructional content meets quality standards for mathematics learning materials. Table 3 shows the validation results from both content experts and media experts.

Table 3. Content expert validition

Assessed Aspect	Mean Score	Category
Alignment with the curriculum	3.8	Highly Feasible
Accuracy of mathematical concepts	3.6	Highly Feasible

Assessed Aspect	Mean Score	Category
Clarity of language and presentation	3.4	Feasible
Appropriateness of examples and exercises	3.7	Highly Feasible
Ability to support conceptual understanding	3.6	Highly Feasible
Overall average	**3.6**	**Highly Feasible**

One of the strongest aspects identified in this validation is the alignment of the material with the applicable curriculum, particularly the revised 2013 Curriculum. The media successfully present the linear systems with two variables content in a systematic structure, with a logical learning sequence and a clear emphasis on conceptual understanding rather than merely procedural computation. In addition, the clarity of the presentation of linear systems with two variables problem-solving steps is considered a major strength. Students are guided through the process starting from identifying variables, constructing mathematical models, and solving the equations using substitution or elimination methods, all of which are delivered in a visual and interactive manner. This approach is considered highly effective in strengthening conceptual understanding, which is often abstract when conveyed only through verbal or written explanations. From the perspective of instructional content, the media are therefore regarded as relevant to the basic competencies and learning achievement indicators, capable of fostering students' logical thinking and mathematical problem-solving skills, and providing examples and exercises that are appropriate to the cognitive level of junior high school students. Overall, the content expert validation results indicate that the SIMaV media are categorized as feasible to highly feasible for use in mathematics instruction. The content experts assessed that the media presents content in accordance with the Grade VIII curriculum and the pedagogical principles of mathematics.

Media Expert Validation

Meanwhile, the results of the media expert validation indicate that the media obtained an average score of 3.5 out of 4, which falls into the "Feasible" category in Table 4. This assessment was based on several technical and aesthetic indicators, including visual design, navigation, interactivity, and system stability.

Table 4. Media expert validation

Assessed Aspect	Mean Score	Category
Visual design	3.6	Highly Feasible
Navigation and ease of use	3.4	Feasible
Interactivity and button functionality	3.5	Feasible
System response speed	3.4	Feasible
System stability and minimal errors	3.6	Highly Feasible
Overall average	**3.5**	**Feasible**

One of the aspects most appreciated by the media experts was the interface design, which was considered attractive and interactive through the effective use of colors, icons, and layout that support the learning process. This design was found to enhance students' focus and engagement during learning activities. The navigation of the media also received positive

evaluation, as it was designed to be intuitive and user-friendly, allowing users both teachers and students to easily access materials, select menus, and return to the main page without technical difficulties. Another notable strength was the minimal occurrence of errors or technical disruptions during media testing. All buttons functioned properly, transitions between slides ran smoothly, and the automatic feedback features in the interactive questions operated as intended. This indicates that the media were developed using stable macro programming and are compatible with the Microsoft Office environment.

Nevertheless, the media experts suggested that concise and clear usage instructions be provided on the initial display of the media to ensure that new users can optimally utilize all available features. Overall, validation results from both content experts and media experts indicate that the SIMaV media fall within the feasible to highly feasible categories for use in junior high school mathematics instruction. The media meet both content and technical criteria required to support effective, engaging, and learner-oriented instruction. Overall, the media experts concluded that the interface design of the media is attractive, the navigation is easy to understand, and the macro programming is stable with no significant errors.

3.1.4. Implementation

The media was implemented with 30 eighth-grade students. A pretest-posttest design and a student response questionnaire were administered. To examine the effectiveness of SIMaV media in improving students' mathematical abstraction ability, measurements of students' initial ability (pretest) and final ability (posttest) were conducted before and after the use of the media. The tests consisted of similar items focusing on abstraction ability, mathematical modeling, and solving Systems of Two-Variable Linear Equations.

To more accurately measure the level of improvement in students' learning outcomes, the N-Gain formula was applied. The results indicate that learning using SIMaV media led to a considerable improvement in students' mathematical abstraction ability, although there remains room for further refinement and development.

Students improved their learning outcomes from a low initial level to higher achievement, particularly in their ability to recognize relationships between variables, generalize solution patterns, and translate problem situations into algebraic and graphical representations. The effectiveness of the media could be further enhanced through additional practice exercises, more intensive interactive discussions, and more optimal use of learning time.

Table 5. Results of the data normality test

Residuals	W	p
Pretest	0.981	.453
Posttest	0.989	.875

Note. Significant results suggest a deviation from normality

Based on the results presented in Table 5, the Shapiro–Wilk normality test showed that the significance value (p) for the pretest data was 0.453 and for the posttest data was 0.875. Both values are greater than 0.05, indicating that the pretest and posttest data are normally distributed. Therefore, the assumption of normality for parametric analysis has been fulfilled,

and the data are appropriate for further analysis using parametric statistical tests such as the independent samples t-test.

Table 6. The results of the homogeneity of variance test

	F	df$_1$	df$_2$	p
Pretest	1.271	1	58	.264
Posttest	12.105	1	58	< .001

Based on the results present in Table 6, the homogeneity of variance test using Levene's Test, the pretest data show a significance value of 0.264 (p > 0.05), indicating that the variances among groups are homogeneous. This suggests that before the treatment, the initial conditions of the research subjects were relatively similar. In contrast, the posttest data show a significance value of less than 0.001 (p < 0.05), which indicates that the variances are not homogeneous. This means that after the treatment was applied, there were significant differences in variability among the groups. Therefore, it can be concluded that the groups were homogeneous at the beginning of the study, but became heterogeneous after the intervention.

Table 7. The results of descriptive statistical analysis for the experimental and control groups

	Group	N	Mean	SD	SE	Coefficient of variation
Pretest	experiment	30	51.77	15.56	2.842	0.301
	control	30	37.73	12.85	2.346	0.341
Posttest	experiment	30	82.00	13.24	2.418	0.162
	control	30	57.93	21.99	4.014	0.380

Based on the descriptive statistical analysis in Table 7, both the control and experimental groups consisted of 30 students in the pretest and posttest. In the pretest, the experimental group showed a higher mean score (51.77) than the control group (37.73), indicating better initial performance. The standard deviations (15.56 for the experimental group and 12.85 for the control group) suggest moderate variability in both groups. The coefficients of variation also indicate that the control group had slightly more consistent scores than the experimental group at the pretest stage. In the posttest, both groups experienced an increase in mean scores, indicating improvement after the treatment. However, the experimental group showed a substantially higher mean score (82.00) compared to the control group (57.93), suggesting that the treatment had a stronger positive effect on the experimental group. In addition, the experimental group had a lower standard deviation (13.24) and coefficient of variation (0.162) than the control group, indicating more consistent performance. Overall, these results show that although both groups improved, the experimental group demonstrated greater achievement and more stable learning outcomes after the intervention.

Table 8. The results of the independent samples t-test

	t	df	p
Pretest	3.808	58	< .001
Posttest	5.136	58	< .001

Based on the results of the independent samples t-test in Table 8, there was a statistically significant difference between the control and experimental groups in both the pretest and posttest. In the pretest, the obtained t-value was 3.808 with df = 58 and a significance value of less than 0.001 (p < 0.001), indicating a significant difference in initial performance between the two groups. This suggests that the groups were not equivalent at the beginning of the study. Similarly, in the posttest, the t-value was 5.136 with 58 degrees of freedom and a significance value of less than 0.001 (p < 0.001), showing a highly significant difference in post-intervention performance between the groups. This result indicates that the experimental group outperformed the control group after the treatment. Furthermore, the note indicates that Levene's test was significant (p < 0.05), suggesting a violation of the assumption of equal variances. Therefore, the interpretation of the t-test results should consider the possibility of unequal variances. Nevertheless, the consistently significant findings demonstrate that there were meaningful differences between the two groups, particularly after the implementation of the treatment.

Table 9. The N-Gain calculation

Group	N-Gain	Category
Experimental	0.63	Moderate (approaching high)
Control	0.32	Moderate

Based on the N-Gain calculation in Table 9, the experimental group achieved an N-Gain value of 0.63, which is also classified as moderate but close to the high category. Meanwhile, the control group obtained an N-Gain value of 0.32, which falls into the moderate improvement category. This indicates that conventional learning was able to improve students' performance, but the improvement was relatively limited. This result shows that the implementation of SIMaV (System Instructional Macro-Visualization) led to greater learning improvement compared to conventional instruction. The difference in N-Gain values between the two groups indicates that the use of SIMaV was more effective in enhancing students' mathematical abstraction ability. Students in the experimental group not only experienced significant improvement in learning outcomes but also demonstrated more optimal development of conceptual understanding. Therefore, the results of the N-Gain analysis strengthen previous findings that SIMaV is an effective instructional medium for improving students' mathematical abstraction ability more maximally than traditional teaching methods.

Based on the results of the data analysis, including the homogeneity test, descriptive statistics, and independent samples t-test, it can be concluded that the implementation of SIMaV (System Instructional Macro-Visualization) had a positive impact on improving students' mathematical abstraction ability. The descriptive statistical results show that in the posttest, the experimental group that used SIMaV achieved a much higher mean score than the
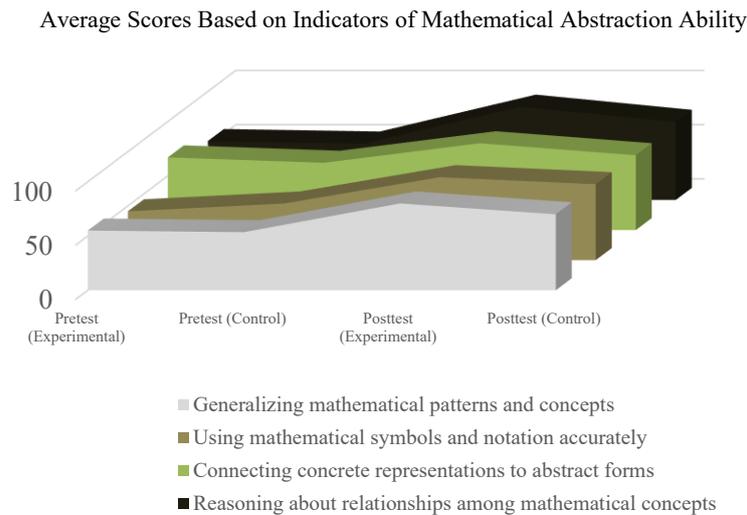
control group. In addition, the experimental group demonstrated lower score variability, indicating that the improvement in learning outcomes was more consistent among students. This suggests that SIMaV effectively helps students understand mathematical concepts in a more structured and systematic way through macro-level conceptual visualization.

Furthermore, the independent samples t-test results revealed a significant difference between the experimental and control groups in the posttest (p < 0.001). This finding indicates that learning using SIMaV was significantly more effective in enhancing students' mathematical abstraction ability compared to conventional instruction. Although there was a significant difference between the groups in the pretest, the greater improvement observed in the experimental group after the intervention highlights the positive contribution of SIMaV. In addition, the homogeneity test showed that the posttest variances were not homogeneous, reflecting differences in students' learning development. However, the experimental group exhibited better score consistency, which strengthens the evidence that SIMaV not only improves learning outcomes but also supports more stable conceptual understanding.

Furthermore, based on the results of the independent samples t-test and the N-Gain analysis, it can be concluded that the implementation of SIMaV (System Instructional Macro-Visualization) had a significant positive effect on students' mathematical abstraction ability. The t-test results indicate statistically significant differences between the experimental and control groups in both the pretest and posttest (p < 0.001). Although the groups were not equivalent at the beginning of the study, the posttest results show that the experimental group achieved substantially better performance after the intervention, demonstrating the effectiveness of SIMaV in supporting conceptual understanding and abstraction. Furthermore, the N-Gain analysis strengthens these findings by showing that the experimental group obtained a higher N-Gain value (0.63) compared to the control group (0.32).

While both groups were classified in the moderate improvement category, the experimental group's gain was close to the high category, indicating a more substantial learning improvement. This suggests that SIMaV enabled students to better construct and internalize abstract mathematical concepts through macro-level visual representations. Overall, the combination of significant t-test results and higher N-Gain scores provides strong empirical evidence that SIMaV is an effective instructional system for enhancing students' mathematical abstraction ability and promoting more meaningful and sustained learning outcomes.

Overall, these findings support the conclusion that the design and implementation of SIMaV as a conceptual macro-visualization system significantly enhance students' mathematical abstraction ability. Therefore, SIMaV can be recommended as an innovative and effective instructional medium for fostering higher-level mathematical thinking and abstraction skills.

Average Scores Based on Indicators of Mathematical Abstraction Ability

■ Generalizing mathematical patterns and concepts
■ Using mathematical symbols and notation accurately
■ Connecting concrete representations to abstract forms
■ Reasoning about relationships among mathematical concepts

Figure 6. Average scores based on indicators of mathematical abstraction ability

The average scores of students' mathematical abstraction ability are presented based on four indicators in Figure 6, namely generalizing mathematical patterns and concepts, using mathematical symbols and notation accurately, connecting concrete representations to abstract forms, and reasoning about relationships among mathematical concepts, in both the experimental and control classes at the pretest and posttest stages. At the pretest stage, both the experimental and control classes showed relatively moderate scores, with the experimental class tending to perform slightly better on the indicator of connecting concrete representations to abstract forms.

This finding is consistent with previous studies indicating that students often experience difficulties in abstraction when learning algebraic concepts without sufficient visual support. After the treatment (posttest), a significant increase in scores was observed in the experimental class across all indicators, with the highest scores found in the indicators of reasoning about relationships among mathematical concepts and generalizing mathematical patterns and concepts. The improvement supports research findings by Nurwita et al. (2025), that interactive and visual-based instructional media can effectively facilitate students' transition from concrete representations to abstract mathematical thinking.

Meanwhile, the control class also experienced improvement, but not to the same extent as the experimental class, which aligns with studies reporting that conventional instruction tends to provide limited opportunities for deep conceptual exploration. Then overall, the graph indicates that learning in the experimental class was more effective in improving students' mathematical abstraction ability than in the control class. Therefore, it can be concluded that SIMaV media is more effective than conventional instructional methods in enhancing students' understanding of the concepts of Systems of Linear Equations in Two Variables. These findings strengthen the argument that the use of interactive visualization-based media such as SIMaV can create a more engaging, meaningful, and contextual learning experience, thereby supporting the achievement of more optimal learning outcomes in modern mathematics education.

3.1.5. Evaluation

After the SIMaV media was implemented in the learning process, data analysis was conducted on validation results, student responses, and learning outcomes. Student responses were measured using a closed-ended questionnaire to determine the extent to which the media attracted students' attention, facilitated understanding, and increased their interest in learning mathematics. Therefore, the media has positive pedagogical and psychological value in supporting the student learning process in Table 10.

Table 10. Student responses to the learning media

Statement	Average Score	Positive Percentage	Category
The media is interesting and not boring	3.6	90%	Very Positive
Easy to understand SLETV	3.5	87%	Very Positive
The media is easy to use without teacher assistance	3.4	85%	Positive
Increases interest in learning mathematics	3.5	88%	Very Positive
Willing to use similar media for other topics	3.6	85%	Very Positive
Overall average	**3.5**	**87%**	**Very Positive**

Based on the questionnaire results, the following findings were obtained; a) 90% of students stated that the SIMaV media was interesting and enjoyable. Students felt supported by the colorful visual displays, the use of animations, interactive buttons, and the varied presentation of problems. These features made the learning atmosphere more engaging and less monotonous, b) 87% of students reported that they found it easier to understand the linear systems with two variables material after using the media. The visualization of problem-solving steps and the presentation of questions accompanied by immediate feedback helped students understand the concepts and procedures of Systems of Linear Equations in Two Variables gradually (Wang et al., 2022), and c) 85% of students expressed their interest in using similar media for other mathematics topics. This indicates that students felt comfortable and well-matched with the learning approach using SIMaV media and were motivated to continue using it as a learning aid.

The overall average score from the student response questionnaire was 3.5 out of 4, which is categorized as Very Positive (see Table 10). This indicates that the developed media successfully provided an engaging learning experience, supported abstract thinking, and encouraged students' motivation to continue learning using a similar approach. These results reflect that SIMaV media is not only effective in terms of content and technical aspects but is also very well accepted by students. Students' interest in the media is an important factor in determining learning success, especially for topics that require conceptual understanding and logical reasoning such as linear systems with two variables (Abdul Latif et al., 2024; Taşkın & Kılıç Çakmak, 2023). The media also proved effective in reducing boredom, increasing students' focus during learning, and providing opportunities for independent exploration.

3.2. Discussion

The results of this study indicate that the SIMaV (Simulation and Macro Visualization) media significantly enhance students' mathematical abstraction ability in learning Systems of Two-Variable Linear Equations. This finding is consistent with previous studies emphasizing that students' main difficulties in algebra arise from weak connections between symbolic manipulation, graphical interpretation, and contextual understanding. Ding (2021) state that traditional instruction that prioritizes procedural fluency without conceptual grounding often leads students to solve equations mechanically, without understanding the underlying mathematical relationships. The SIMaV media address this issue by providing dynamic and interactive visualizations that explicitly link algebraic symbols with their graphical representations and real-world contexts. The analysis phase of this study revealed that students struggled to interpret the meaning of intersection points and the relationships between coefficients and graphical changes (Li & Fan, 2024; Selowa & Dhlamini, 2023). Similar findings were reported by Turan and Karagöz Akar (2024) who argued that abstraction in algebra develops most effectively when learners are supported by visual mediators that allow them to explore variation and invariance. By enabling students to manipulate coefficients and instantly observe changes in line positions, SIMaV fosters relational thinking rather than isolated procedural execution. This supports the theory that abstraction emerges through coordinated use of multiple representations.

From a design perspective, the use of macro-based interactive media within Microsoft Office offers pedagogical advantages, particularly in contexts with limited technological infrastructure. Previous research has shown that interactive multimedia environments can reduce cognitive overload and improve conceptual understanding when visual, symbolic, and textual information are well integrated. The structured interface, intuitive navigation, and immediate feedback mechanisms in SIMaV align with principles of multimedia learning, which state that learners understand concepts more deeply when they actively engage with visual representations rather than passively receiving information. The specific features of the SimaV media, particularly macro-visualization and dynamic changes, are designed to concretely operationalize abstraction theory and multimedia learning principles. Macro-visualization enables abstract mathematical concepts to be presented through structured and comprehensive visual representations, so students do not rely solely on mental construction based on formal symbols. By providing clear visuals that focus on essential elements, irrelevant information can be minimized, thereby reducing students' extraneous cognitive load. Meanwhile, the dynamic change feature helps students observe relationships among concepts in a gradual and continuous manner, for example through shifts, changes in values, or directly observable visual transformations. This process supports the construction of conceptual meaning without requiring excessive information processing in working memory. Furthermore, the simultaneous integration of visual and symbolic representations in SimaV encourages dual coding, namely the processing of information through visual and verbal channels at the same time. Consequently, students have the opportunity to connect mathematical symbols with their visual meanings, which ultimately can strengthen conceptual understanding and enhance mathematical abstraction ability.

The validation results from content and media experts further confirm the quality of SIMaV as an instructional medium. High feasibility ratings for curriculum alignment, conceptual accuracy, and clarity of presentation indicate that the media meet pedagogical standards for effective mathematics instruction. Zhang et al. (2025) state that visualization-based learning media are more effective when they emphasize conceptual coherence and logical progression rather than isolated examples. Media expert evaluations also highlighted the importance of usability and system stability, which are critical factors in determining whether instructional technology can be sustainably implemented in classroom settings (Hidayat & Aripin, 2023; Hidayat et al., 2025; Hidayat et al., 2022; Wang et al., 2020).

The implementation results provide strong empirical evidence of the effectiveness of SIMaV media. The experimental group showed significantly higher gains in mathematical abstraction ability compared to the control group, as indicated by both paired and independent t-test analyses. This finding corroborates international studies demonstrating that students who learn algebra through interactive visualization environments outperform those who receive conventional instruction. The moderate N-Gain score suggests that while SIMaV has a meaningful impact, further enhancement-such as extended learning time or richer problem variations-could yield even stronger results.

Analysis based on abstraction indicators reveals that SIMaV is particularly effective in improving students' ability to reason about relationships among mathematical concepts and to generalize mathematical patterns. These skills are fundamental components of mathematical abstraction and higher-order thinking. The results support findings by Ding et al. (2022) who reported that students' abstraction abilities develop more robustly when learning activities encourage exploration, representation switching, and reasoning rather than direct instruction alone. In contrast, the lower gains observed in the control group are consistent with studies showing that conventional instruction often limits opportunities for deep conceptual engagement. Beyond cognitive outcomes, students' responses indicate that SIMaV media positively influence affective aspects of learning. High levels of interest, enjoyment, and motivation reported by students align with previous research suggesting that engaging visual media can reduce mathematics anxiety and foster positive learning attitudes. Motivation plays a crucial role in sustaining students' engagement with abstract mathematical concepts, and the positive reception of SIMaV suggests that such media can support both cognitive and emotional dimensions of learning. So, this study reinforces the growing body of evidence that interactive visualization-based media are effective tools for enhancing mathematical abstraction ability. By bridging symbolic, graphical, and contextual representations within an accessible technological platform, SIMaV provides meaningful learning experiences that support deeper conceptual understanding and higher-order thinking. These findings suggest that macro-based visualization media can serve as a practical and scalable solution for improving algebra instruction, particularly in educational contexts with limited access to advanced digital technologies. Future research may focus on longitudinal effects, adaptation to other algebraic topics, and integration with inquiry-based or collaborative learning approaches.

The implications of this study for instructional practice indicate that SimaV media can serve as a strategic alternative for mathematics educators in helping students understand

abstract concepts in a more meaningful way. Through the use of macro-visualization and dynamic changes, teachers can present learning materials in a more concrete, structured, and accessible manner, so that instruction does not focus solely on symbolic procedures but also emphasizes conceptual understanding. For curriculum developers, these findings provide empirical support for integrating visual-dynamic learning media into the design of mathematics curricula, particularly for topics that require a high level of abstraction. Such integration can be realized through the provision of digital learning resources that align with learning outcomes and promote active student engagement. From a theoretical perspective, the macro-visualization approach embodied in SimaV makes an important contribution to the field of mathematics education research, especially by enriching the understanding of how large-scale visualizations can support mathematical abstraction processes.

The results strengthen abstraction theory and multimedia learning theory by demonstrating that integrated and dynamic visual representations function not merely as illustrative aids, but also as cognitive tools that facilitate concept formation. Thus, SimaV contributes to the development of a theoretical framework that emphasizes the role of visualization as a bridge between concrete and symbolic representations in mathematics learning, while also opening opportunities for further research on the design of macro-visualization-based learning media across diverse educational contexts.

This study has several limitations that need to be stated explicitly. First, the relatively limited sample size and the involvement of participants from a specific school context and grade level restrict the generalizability of the findings to a broader population. Second, the relatively short duration of the SimaV media implementation may have prevented students' mathematical abstraction ability from developing optimally. Third, this study focused on only one specific mathematics topic. Therefore, the effectiveness of SimaV on other topics with different characteristics cannot yet be comprehensively concluded. In addition, the N-Gain score, which falls within the moderate category, indicates that although SimaV has a meaningful impact on improving students' mathematical abstraction ability, there remains room for further development. Accordingly, future studies are recommended to involve larger and more diverse samples, extend the duration of instruction, and integrate a wider range of richer and more challenging problems. Further research may also examine the application of SimaV to other mathematics topics or at different educational levels in order to obtain a more comprehensive understanding of the effectiveness and sustainability of this media.

4.   CONCLUSION

The design process for the SIMaV learning media on Systems of Linear Equations in Two Variables was successfully carried out by following the ADDIE model, starting with needs analysis, design, development, implementation, and evaluation. The developed media was categorized as feasible to highly feasible for learning based on validation results from subject matter and media experts. In addition, students' responses were very positive, as the media was found to be interesting, easy to understand, and helpful in enabling them to visually comprehend the relationship between equation forms and the graphs of the System of Linear Equations in Two Variables.

The effectiveness test results also showed that the SIMaV media improved students' mathematical abstraction ability, as indicated by a higher average posttest score than the pretest and an N-Gain value in the moderate range. Therefore, this media has been proven effective and can be used as an alternative, innovative learning medium that enhances students' motivation and conceptual understanding.

This study also recommends that teachers be encouraged to use SIMaV media as a learning aid, especially for topics requiring visualization and simulation of concepts. Furthermore, students can use SIMaV media as an engaging and interactive tool for independent learning. For future similar research, it is recommended to develop SIMaV media for other mathematics topics or to integrate it with web- and mobile-based platforms to reach a wider audience.

Acknowledgments

Declarations

Author Contribution	: L: Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, and Writing - review & editing; WH: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Writing - original draft, and Writing - review & editing.
Funding Statement	: The author discloses no receipt of the following financial support for this article's research, authorship, and publication.
Conflict of Interest	: The authors declare no conflict of interest.
Additional Information	: Additional information is available for this paper.

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