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Development of Multimedia-Based Teaching Materials to Improve Mathematical Communication Skills in the Context of Statistical Literacy

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Abstract

This study aims to develop multimedia-based teaching materials grounded in statistical literacy to improve students' mathematical communication skills. The development process employed the ADDIE model. The quality of the product was determined based on three criteria: validity, practicality, and effectiveness. Validity was evaluated by experts using established feasibility standards (≥85% categorized as very valid), practicality was assessed through teacher and student responses, and effectiveness was measured using a paired-sample t-test supported by learning gain analysis. The results show that the developed multimedia achieved high validity (material expert = 87.5%, media expert = 93.5%, learning expert = 94.45%), indicating that the content, design, and pedagogy are appropriate for learning. Practicality results revealed positive responses from students (84.9%) and teachers (87.5%), suggesting that the multimedia is easy to use and supports classroom implementation. Furthermore, the effectiveness test showed a significant improvement in students' mathematical communication skills (mean score increased from 62.19 to 84.46; $p < 0.05$), which is supported by an average N-gain score of 0.523, categorized as medium. This indicates that the integration of statistical literacy contexts within multimedia facilitates students in interpreting, representing, and communicating data meaningfully. These findings demonstrate that multimedia grounded in statistical literacy not only enhances student engagement but also supports the development of mathematical communication skills through contextual data interpretation processes.

Keywords: Development, Teaching Materials, Multimedia, Mathematical Communication Skills, Statistical Literacy.

1. Introduction

This study situates multimedia, statistical literacy, and mathematical communication skills within a unified conceptual framework to address the need for meaningful mathematics learning. Multimedia functions as a cognitive and visual tool that enables students to interact dynamically with data, while statistical literacy provides a contextual foundation for interpreting, analyzing, and evaluating real-world data. Mathematical communication skills, in turn, refer to students' ability to express their understanding through written, visual, and verbal representations. The integration of these components is expected to support not only conceptual understanding but also effective communication of data-based insights. However, previous studies have often examined multimedia use or mathematical communication skills separately, with limited attention to the mediating role of statistical literacy.

Mathematical communication includes a procedure for expressing mathematical ideas through symbols, graphs, media and mathematical language, both orally and in writing, to solve problems in mathematics (Dwi, Rasyidi, Akbar, & Mustari, 2024). It is considered one of the essential competencies in mathematics learning (Karsim, Ratnaningsih, & Rahayu, 2023). The development of communication skills has been shown to improve when supported by appropriate instructional resources, indicating that teaching materials play an important role in fostering students' ability to communicate mathematically (Fadila, Wahyuni, & Budirso, 2023). Teaching materials themselves are systematically designed resources that support learning objectives and instructional processes (Ekarini, 2024).

In the context of rapid advancements in information and communication technology, the availability of interactive teaching materials has become essential in mathematics education. Multimedia-based teaching materials, which integrate text, images, audio, animation, and video, have been shown to enhance engagement and support conceptual understanding (Daulay & Ridhatullah, 2023), while also fostering skills such as creativity, digital literacy, and independent learning (Staneviciene & Žekien˙, 2025). Furthermore, mathematical communication skills are closely related to the ability to interpret and communicate mathematical ideas effectively. The National Council of Teachers of Mathematics (NCTM, 2000) emphasizes that students need the ability to comprehend, interpret, analyze, and evaluate mathematical thinking, as well as to communicate data-based information in everyday life, both orally and in writing. These skills are essential for achieving meaningful learning outcomes (Andrianingsih, Waluya, & Sugianto, 2021).

To address these needs, this study employs a Research and Development (R&D) approach using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), which provides a systematic framework for developing effective instructional products (Nauman et al., 2020). The novelty of the method in this research lies in the development of multimedia teaching materials that are not only oriented towards the use of interactive technology, but also systematically integrate the context of statistical literacy in learning design to measure

mathematical communication skills, R&D research with contextual literacy-based design, thus producing products that are not only valid and practical, but also contextual to students' data literacy skills.

Previous studies have shown that teaching materials can support effective evaluation and meaningful learning (Lavrenteva & Orland-barak, 2023). Statistical literacy itself is an essential skill for analyzing, interpreting, and evaluating data as evidence (Ratnawati, Siswono, & Rani, 2022). In addition, multimedia-based teaching materials have been proven to improve students' motivation, understanding, and thinking skills. Therefore, this study was conducted at SMPN 1 Suralaga, East Lombok, focusing on seventh-grade students, with the aim of improving students' mathematical communication skills (Fajriati & Murtiyasa, 2023).

2. Method

This research methodology used the R&D method with the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model. This research was conducted at SMPN 1 Suralaga with a target population of four classes of seventh-grade junior high school students, with a total target population of 110 students. If a computer device that facilitates learning (multimedia) satisfies the requirements of validity, practicality, and effectiveness, it can be deemed to be of high quality.

Each stage of the ADDIE model was implemented systematically:

1) Analysis: Identification of students' difficulties in data presentation and communication skills through observation and interviews.
2) Design: Preparation of multimedia structure, learning objectives, statistical literacy tasks, and communication indicators.
3) Development: Creation of interactive multimedia using text, animation, video, and quizzes, followed by expert validation.
4) Implementation: Limited and field trials involving students and teachers.
5) Evaluation: Assessment of validity, practicality, and effectiveness.

The instruments used included validation sheets (based on content, pedagogy, language, and media aspects), practicality questionnaires, and a mathematical communication skills test. Effectiveness was analyzed using paired-sample t-test and supported by the calculation of learning gain to determine the magnitude of improvement.

3. Results and Discussion

3.1 Results

The results of this study present the specifications of multimedia-based teaching materials and the validation results from validators consisting of material experts, multimedia experts, and learning experts. This study also tests the practicality of the developed teaching materials based on teacher and student feedback, and evaluates the effectiveness of multimedia-based teaching materials in improving junior high school students' mathematical communication skills, with a focus on the context of statistical literacy.

In the development stage of multimedia-based teaching materials in this study, it has been tested on several subjects, namely multimedia design experts, material experts, learning experts, class teachers, and seventh grade junior high school students. This teaching material is interactive because it allows student interaction. Students can give commands to the teaching material and the teaching material can provide feedback to students. Specific multimedia components consist of covers, menus, buttons, navigation, videos, voice-overs, audio, images, materials, writing forms, colors, quiz questions, and instructions for use. Some examples of images of multimedia-based teaching materials that were created are as follows.

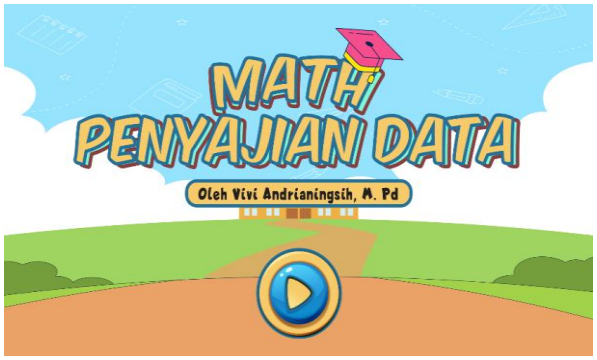


Figure 1. Product Opening View

Figure 2. Menu/Main Display

Figure 3. Material Display

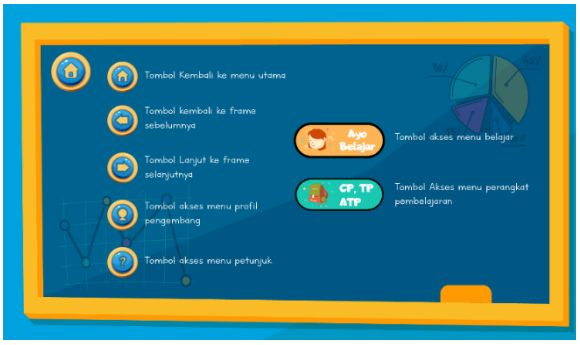


Figure 4. Display of usage instructions/Navigation

1. Validation Results of Multimedia-Based Teaching Materials

The validation results were carried out by 3 validators, namely by the material expert validator, multimedia expert and learning expert by distributing questionnaires using a Likert scale. The validity data for multimedia teaching materials was obtained from a questionnaire compiled based on 7 indicators, namely (1) Content/material aspect, (2) Learning/pedagogical aspect, (3) Language aspect, (4) Multimedia display, (5) product attractiveness, (6) clarity of instructions, (7) and technical feasibility. The first validation process was carried out by the material expert, Mr. Ahmad Masroni S.Pd., M.Pd., who gave a score of 63 or 87.5%. Then, validation by the multimedia

expert was carried out by Mr. Nukman Sn. S.Kom., M.Kom., with a score of 67 or 93.5%. Finally, validation was carried out by the learning expert, Mrs. Widia Arni, S.Pd., who gave a score of 68 or 94.45%. The complete feasibility calculation can be seen in the table below.

Eligibility percentage = $\frac{STotal\ core\ obtained}{Maximum\ Score}$ x 100

Table 1. Presents the criteria used to evaluate the feasibility of the developed multimedia-based teaching materials. These criteria classify the level of eligibility based on percentage scores obtained from expert validation.

Tabel 1. Criteria for Evaluating the Feasibility of Multimedia-Based Teaching Materials

Percentage (%)	Criteria
85-100	Very Eligible
70-84	Eligible
55-69	Quite Eligible
<55	Not Eligible

Even with slight changes to the content/material, language, technological elements, and multimedia quality, the validation study shows that the created multimedia-based instructional materials fulfill the requirements of being highly suitable or meeting the standards of being very valid for testing. The table below displays the recommendations and feedback received.

Table 2. Description of the Results of the Revision of Multimedia Teaching Materials

Aspects	Suggestions for improvement	Revision results
Material	1. Advertising images in the materials must be relevant to the material being studied.	1. The advertising images in the material are clarified and adapted to the material being studied.
Learning Material Design	1. Lettering and wording must be standard. 2. The initial display should display information on teaching materials and CP, TP, and ATP. 3. Icons in image form are lacking. 4. Audio quality should be improved. 5. Bugs or errors/loading.	1. Standardized letter and word writing. 2. The initial display displays data presentation materials and learning objectives. 3. Added image icons. 4. Improved audio quality.
Language	1. The words and sentences used do not adhere to Indonesian language rules in accordance with EYD.	1. The words and sentences used in interactive multimedia-based teaching materials are adapted to Indonesian language rules that are in accordance with EYD.

2. Practicality Test Results

The practicality of the developed teaching materials was evaluated based on student and teacher responses to the learning process using multimedia-based teaching materials. The following data summarizes student and teacher responses regarding the use of interactive multimedia-based teaching materials:

a. Trial (Limited Scale) of Multimedia-Based Teaching Materials

Following the validation and revision of the interactive multimedia-based teaching materials based on recommendations and input from learning experts, material experts, and multimedia expert validators, this trial was carried out. The purpose of this small-scale experiment was to assess the initial viability of employing multimedia-based instructional resources. A questionnaire given to a small sample of participants served as the tool for gathering information on the viability of the multimedia-based teaching resources. Ten seventh-grade kids from SMPN 1 Suralaga were chosen at random to make up this small group.

The feasibility of the multimedia quality, the content, and the usefulness of the teaching materials in supporting mathematics learning activities in the data presentation section were all evaluated based on student responses during the practicality stage of this limited trial. Table 3 displays the limited trial questionnaire responses.

Table 3. Limited trial score

No	Student Name	Grade
1	Baiq Nadia Sa'ada Tina	89
2	Bambang Prayoga	78
3	Desti Masriani Ulpia	81
4	Gafil Al Azan	85
5	Gilang Anugerah Prasetya	84
6	Haerul Azmi	89
7	Lalu Muh Iqbal Wirahadi Kusuma	78
8	M Ziad Zanki Hakiki	92
9	Frifka Azima	85
10	Sima Azkia Rosada	88
	Total	849
	Average	**84,9**

It is evident that throughout the limited-scale trial phase, students' responses to the usage of multimedia-based teaching materials had an average score of 84.9%. Additionally, a math

instructor named Mrs. Finta, S.Pd., was given a questionnaire and received an 87.5% score. This score places multimedia-based instructional resources in the Very Practical category, indicating that they are useful for the learning process.

b. Field Trial of the Use of Multimedia-Based Teaching Materials

The next trial was a field trial conducted by soliciting responses from teachers and 26 students. This test was the final stage of the feasibility or practicality category of the developed teaching materials. The following describes teacher and student responses to the use of multimedia-based teaching materials.

1) Teacher and Student Responses to Multimedia-Based Teaching Materials

A field trial is the following step, during which teachers and students are asked for their opinions. The last phase of the generated teaching materials' viability or practicality category is this testing. The reactions of educators and learners to the usage of multimedia-based instructional resources are described here.

2) Teacher response to the use of multimedia teaching materials

The data from the teacher response questionnaire regarding the use of multimedia-based teaching materials are as shown in Table 4 below.

Table 4. Results of teacher responses regarding product practicality

No	Scale Indicator	Assessment			
		1	2	3	4
1	Learning materials are easy to understand				√
2	Suitability of the material to student needs				√
3	Use of appropriate language in explaining the material			√	
4	Suitability of problem-solving materials to CP/TP			√	
5	Suitability of the material to indicators				√
6	Clarity of learning instructions			√	
7	Correctness of material descriptions to problem-solving				√
8	Learning activities can motivate students			√	
9	Appropriate font color selection				√
10	Providing exercises to supplement the material			√	
11	Choosing interesting images to motivate students				√
12	Interactive multimedia-based teaching material display design				√
13	Font size and font type			√	
14	Clarity of narrative			√	
15	Ease of use				√
16	Based on multimedia technology				√
17	Practical in application				√
18	In keeping with current developments			√	
	Total	63			

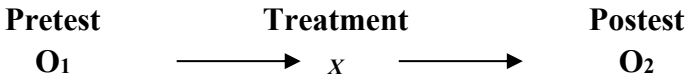
According to Table 4, the teacher response questionnaire received a total score of 63, or 87.5%. According to teacher answers, the multimedia-based teaching materials' practicality level was 87.5%, which is considered very practical. Teachers who completed the practicality sheet also indicated that they thought the multimedia-based teaching materials were highly appropriate for seventh-grade junior high school students, particularly when it came to helping them improve their literacy and mathematical communication skills regarding data presentation. In addition to being engaging, these interactive multimedia teaching materials are also easy to understand, thus helping students learn more optimally.

3) Student response to the product developed

Practicality data from the student questionnaire was compiled based on nine indicators, namely: (1) the appearance of the teaching materials, (2) the size and shape of the letters, (3) the suitability of the illustrations, (4) the combination of colors, (5) the attractiveness of the product, (6) the clarity of the instructions, (7) the clarity of the material, (8) the use of language, and (9) the level of ease of the material to be understood. Based on the analysis of the questionnaire filled out by students using a Likert scale according to these indicators, an average score of 32.62 was obtained, equivalent to 90.60%. These results indicate that the practicality of multimedia-based teaching materials according to students reached 90.60% and was included in the very practical category.

c. Results of the Effectiveness Test of Multimedia-Based Teaching Materials

The effectiveness of the created multimedia teaching resources is assessed using the paired sample T-test. The normalcy test is performed as a preparatory test before the paired sample T-test. The efficacy of the product in the form of multimedia-based instructional materials is then evaluated using a paired sample T-test. Students' mathematical communication abilities are assessed using the instructional materials both before and after therapy (pretest and posttest).The research design can be seen in the following figure (Sugiyono, 2012).



a. Data Normality Test

After determining whether the data is normal, a paired sample t-test can be run. Put differently, a normalcy test is a precondition for a paired sample t-test. The pretest and posttest results are the data to be evaluated for normalcy. As a result, the hypothesis for the normality test is: 0 = Data is normally distributed; 1 = Data is not normally distributed. SPSS was used to process the data. Because the data utilized is a small sample (<30), the Shapiro Walk column of the normality test results table can be used to determine the normality of the data. A normal distribution is indicated if the significance value of the normality test result (p-value) is greater than 0.05. The data is not regularly distributed if the significance value (p-value) is less than 0.05. The results of the calculation using SPSS are presented in Table 5 below.

Table 5. Data Normality Test

	Kolmogrov-Smirnov			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
Pretest	.107	26	.200	.966	26	.514
Postest	.126	26	.200	.943	26	.160

*. This is a lower bound of the true significance
a. Lilliefors Significance Correction

Data normality test is the main prerequisite before testing the paired sample t test. From the data normality test with SPSS in table 5. Based on Table 5, it is known that the significance level of the normality test in the Shapiro Wilk test table (<30) has a significance level of 0.514 for the pretest and 0.160 for the posttest so that because the significance level is (p-value) more than 0.05 so that the pretest and posttest data are normally distributed data. From both tests, it shows that the pretest and posttest results are normally distributed.Product Effectiveness Test Results

The effectiveness of multimedia-based teaching materials was measured through a test of students' mathematical communication skills, which was administered using evaluation items in the quiz section of the teaching materials and through a question-and-answer session in class. The evaluation instrument included questions on data presentation to assess students' communication skills in statistical literacy. The effectiveness of this multimedia-based teaching material was tested using a paired-sample t-test with a sample of 26 students, the target population. The research data analyzed were pretest and posttest scores. The hypotheses used in this study to test the significance of the influence were:

H_0 = no significant difference in the use of teaching materials (pretest and posttest scores are the same)

H_1 = there is a significant difference in the use of teaching materials (pretest and posttest scores are different)

Table 6. Paired Sample T-test Results

	Paired Differences					t	Df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Differences				
				Lower	Upper			
Pretest - Postest	-2.226E1	8.28279	1.62439	-25.61472	-18.92374	-13.709	25	.000

H_0 is approved if the SPSS findings indicate a significance level (p-value) > 0.05, indicating that the use of instructional materials is not significantly different. On the other hand, a significant

difference in the use of multimedia teaching materials is indicated if the significance level (p-value) is less than 0.05. Table 6 shows that the significant value (2-tailed) of 0.000 is less than the 0.05 cutoff. This shows that H_1 is accepted and H_2 is rejected, indicating that the instructional materials had a substantial impact. This indicates that students' mathematics communication skills are much enhanced by the use of multimedia-based instructional resources.

Table 7. Table of Descriptive Test Results for Pretest and Posttest

		Mean	N	Std. Deviation	Std.Error Mean
Pair 1	Pretes KKM Awal	62.1923	26	7.53668	1.47806
	Postest KKM Akhir	84.4615	26	6.54969	1.28450

Table 7 displays the average pretest score of 62.19 and the average posttest score of 84.46 for the students' mathematics communication skills test for the usage of multimedia-based teaching resources. This shows that students' communication abilities have significantly improved as a result of using multimedia teaching resources. Thus, it can be concluded that the use of multimedia teaching materials is effective, which is consistent with other study showing that the use of teaching materials is effective in enhancing students' mathematical communication skills (Angraini & Hardi, 2023).

To further examine the magnitude of improvement, the normalized gain (N-gain) analysis was conducted. The N-gain score was calculated using the formula proposed by Richard Hake (1999):

$$\textbf{N-gain} = \frac{\boldsymbol{Postest - Pretest}}{\boldsymbol{100 - Pretest}}$$

The classification of N-gain scores is presented in Table 8.

N-gain Value	Category	Distribution of N-Gain Categories
$g \geq 0.7$	High	4
$0.3 \leq g < 0.7$	**Medium**	17
$g < 0.3$	Low	5

The distribution of students' N-gain categories. The majority of students are in the **medium** category, followed by a smaller proportion in the high and low categories. This distribution indicates that the multimedia-based teaching materials are effective in improving students' mathematical communication skills for most learners.

3.2 Discussion

The findings of this study indicate that the effectiveness of multimedia-based teaching materials is not solely influenced by the use of technology, but by how the multimedia is designed

to support conceptual understanding and communication processes. The integration of statistical literacy contexts plays a key role in providing meaningful learning experiences, as students are encouraged to interpret real-world data and express their reasoning systematically.

Based on the development process, validation outcomes, usefulness, and efficacy of the ensuing multimedia teaching resources, this talk describes these accomplishments. The developed multimedia-based teaching materials, including animations, explanatory videos, interactive illustrations, and context-based exercises, are able to meet students' needs. Data visualization features help students interpret changes, patterns, and comparisons of data, while interactive elements encourage students to be actively involved in learning. The study's findings show that by providing pertinent real-world contexts, interactive multimedia combined with a Contextual Teaching and Learning (CTL) method improves primary school students' motivation, engagement, and math learning outcomes (Pratiwi, Situmorang, & Iriani, 2024). In addition, interactive multimedia is also effective in improving mathematical problem-solving skills and initial mathematical abilities in lower-level students through attractive animation and video displays (Angraini & Fitri, 2023; Y. Sari & Rachmadtullah, 2021).

1. Product Suitability with Learning Needs

The initial needs analysis revealed that students still faced difficulties in understanding data presentation, particularly in interpreting graphs, explaining information verbally and in writing, and connecting data to real-life contexts. Conventional text-based teaching materials were also less effective for students who are more responsive to visual and interactive learning. The developed multimedia-based teaching materials, which include animations, explanatory videos, interactive illustrations, and context-based exercises, were able to address these needs. Data visualization features supported students in identifying patterns, changes, and comparisons, while interactive elements encouraged active engagement, resulting in more meaningful learning.(Plodkaew, Pankaew, Suwanreung, & Komat, 2025).

2. Product Validity Based on Expert Assessment

The validation results from material, multimedia, and learning experts indicated that the developed teaching materials fall into the “very valid” category. Material experts confirmed that the content aligns with Grade VII statistical literacy competencies, including various forms of data presentation and interpretation skills. Multimedia experts highlighted the appropriateness of the design, including clear navigation, consistent visuals, and cognitively appropriate color use. Language and pedagogical experts agreed that the materials are clear, communicative, and aligned with students’ cognitive development and curriculum standards. These findings indicate that the developed materials are suitable for instructional use, consistent with previous studies showing that effective multimedia can enhance students’ understanding and interest in learning statistics (Masrifah, Taufik, & Kusumawardana, 2023).

3. Practicality of the product based on teacher and student assessments

a. Product Practicality Based on Teacher Responses

Practicality was assessed through teacher and student questionnaires, with results indicating a practical category. Teachers reported that the teaching materials were easy to use, adaptable to

various learning models, and efficient in supporting the teaching of data presentation in real-life contexts. However, optimal implementation still requires adequate teacher readiness and technological infrastructure (Setiawi et al., 2024).

b. Product Practicality Based on Student Responses

Students showed positive responses, perceiving the materials as engaging, easy to understand, and supportive in building confidence in communicating data. Interactive features, such as quizzes and diagram simulations, were particularly favored due to the immediate feedback provided. These findings are consistent with previous studies showing that interactive multimedia enhances concentration and comprehension through animations, videos, and simulations (Ibrahim, Rusli, Shaari, & Nallaluthan, 2021) and increases students' motivation and confidence compared to conventional methods Utami & Akhyar, 2023).

c. Product Effectiveness on Mathematical Communication Skills

The field trial demonstrated a significant improvement in students' mathematical communication skills, including the ability to write explanations, verbally interpret data, use graphical representations accurately, and draw appropriate conclusions. Students showed better understanding of data trends, comparisons, and evidence-based reasoning. This indicates that multimedia teaching materials effectively support conceptual understanding and mathematical communication. These results align with studies showing that interactive multimedia, particularly when combined with problem-based learning, enhances learning outcomes and motivation (Harianto & Sudatha, 2023), as well as improves problem-solving skills and conceptual understanding (Adefia & Hidayati, 2022), problem-solving skills and can make it easier for students to understand learning materials (Lisa Meilinda Sari, Rahmawati, & Andayani, 2025), and can improve junior high school students' conceptual understanding according to student needs (Cahaya, Subhan, & Rahmawati, 2022). So that the achievement of students' mathematical communication skills in conveying ideas and opinions on mathematical problems can be conveyed well and there is a significant influence on students' mathematical communication skills (Wahyuni & Yolanda, 2021).

4. Conclusion

The improvement in students' mathematical communication skills can be attributed to key features of the developed multimedia. Data visualization and interactive simulations enable students to observe patterns dynamically, supporting conceptual understanding. The integration of statistical literacy contexts encourages interpretation of real-world data, making learning more meaningful, while interactive quizzes with immediate feedback help refine students' reasoning and explanations.

From a theoretical perspective, these findings align with constructivist learning theory, where knowledge is actively constructed through interaction and representation. Multimedia supports multiple representations (visual, symbolic, and verbal), and statistical literacy provides authentic contexts that enhance students' ability to construct and communicate mathematical meaning effectively.

The results indicate that the developed multimedia-based teaching materials meet the criteria of validity, practicality, and effectiveness. Validity was confirmed by expert evaluations (94.45% from learning experts, 93.5% from multimedia experts, and 87.5% from material experts). Practicality was reflected in positive responses from teachers (87.5%) and students (90.60%). Effectiveness was demonstrated by a significant increase in students' mathematical communication skills, with mean scores rising from 62.19 (pretest) to 84.46 (posttest), supported by a paired sample t-test result of sig. (2-tailed) = .000 ≤ 0.05. This improvement is further reinforced by the N-gain analysis, which yielded an average score of 0.523, categorized as medium, indicating a moderate but meaningful enhancement in students' mathematical communication skills.

These findings suggest that multimedia-based teaching materials can serve as an effective alternative to traditional mathematics instruction, particularly in data presentation topics that support statistical literacy. Statistical literacy inherently involves interpreting and communicating data, which is closely related to mathematical communication skills (Sharma, 2017). In addition to improving conceptual understanding, multimedia encourages students to actively express mathematical ideas verbally and in writing, explain solution processes coherently, and interpret data representations such as tables, graphs, and diagrams. Furthermore, effective implementation requires adequate teacher competence and pedagogical support, highlighting the importance of professional development to enhance instructional practices (Priya & Sangeeta, 2024). The developed product can also be adapted for other topics requiring strong visualization and applied to broader learning contexts.

However, this study has several limitations. It was conducted on a limited sample within a single school, which may affect generalizability. The relatively short implementation period does not fully capture long-term impacts, and the focus on data presentation limits applicability to other mathematical topics.

Therefore, future research should involve larger and more diverse samples, extend the duration of implementation, and explore the use of multimedia-based teaching materials across various mathematical topics. Further studies may also examine the integration of advanced technologies and learning analytics to optimize their effectiveness in enhancing students' mathematical communication skills.

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