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Development Of Pop Up Book Media Based On An Investigative Approach To Improve The Mathematical Communication Skill Of Junior High School Students

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Abstrak

Siswa SMP sering mengalami kesulitan dalam memahami konsep matematika yang abstrak dan membutuhkan bantuan visual dalam proses pembelajaran. Pengembangan media buku pop-up berbasis pendekatan investigasi bertujuan memberikan representasi visual dari konsep matematika. Penelitian ini bertujuan menilai validitas, praktikabilitas, dan efektivitas media buku pop-up berbasis pendekatan investigasi serta mengukur peningkatan kemampuan komunikasi matematis siswa sebelum dan setelah menggunakan buku pop-up. Metode penelitian yang digunakan adalah Penelitian dan Pengembangan (R&D) dengan menggunakan model 4D (*define, design, develop, and disseminate*). Hasil penelitian menunjukkan bahwa media ini sangat valid dari segi media dan materi. Praktikabilitas media ini dinilai sangat praktis, dan efektivitasnya diklasifikasikan sebagai sangat tinggi. Terdapat peningkatan yang signifikan dalam kemampuan komunikasi matematis siswa, yang dikategorikan sebagai tinggi.

Kata kunci: Pengembangan Media, *Pop-Up Book*, Kemampuan Komunikasi Matematis

Abstract

Junior high school students often struggle with grasping abstract mathematical concepts and benefit from visual aids in their learning process. The development of investigative-based pop-up book media aims to provide visual representations of these concepts. This research aims to assess the validity, practicality, and effectiveness of the investigative-based pop-up book media and to measure the improvement in students' mathematical communication skills before and after using the pop-up book. The research methodology employed is Research and Development (R&D) using the 4D model (define, design, develop, and disseminate). The results indicate that the media is highly valid in terms of both media and content aspects. Its practicality is rated as highly practical, and its effectiveness is classified as very high. There is a significant improvement in the mathematical communication skills of junior high school students, categorized as high.

Keywords: *Media Development, Pop-Up Book, Mathematical Communication Skills*

1. INTRODUCTION

Mathematics can be interpreted as a fundamental science that plays a crucial role in the advancement of information, influencing various aspects of life. Mathematics is a discipline with a significant role in the development of human thinking. According to (Nailul, Sunardi, & Sugiarti, 2013) mathematics also plays a vital role in various fields, particularly in science and technology. Mathematics is still considered a challenging subject due to its extensive use of symbols, numbers, and complex theories, making it difficult to understand.

In this context, mathematics needs to be effectively communicated through written or spoken means, ensuring that the information provided can be well understood by others. This aligns with (Cockcroft, 1986) statement that students need to learn mathematics because it serves as a powerful, unambiguous, and precise means of communication. To achieve learning goals, effective communication is essential in the development of mathematics. This is because the communication process aids students in understanding meanings, conveying ideas clearly and accurately, and easily sharing their ideas with others, making information more accessible and understandable. The process of mathematical communication also provides opportunities for students to share ideas (Chung, Yoo, Kim, Lee, & Zeidler, 2016).

Mathematical communication skills, as defined by (Greenes & Schulman, 1996) encompass: 1) The central power students possess in formulating mathematical concepts. 2) Approaches and solutions in mathematical research and investigation. 3) A medium for students to communicate, obtain information, share thoughts and discoveries, evaluate, and refine ideas to convince others. Because of the importance of mathematical communication skills, students are expected to improve their communication skills, aiming to achieve the learning objectives.

Therefore, an appropriate medium is required to address students' problems effectively. The chosen instructional medium should captivate students' interest, ensuring that they remain engaged throughout the learning process. Additionally, the instructional medium should be easy to use without the need for additional resources. One such medium that can be engaging for students and used directly is the pop-up book (Smith, J. A., & Brown, L. K., 2015).

According to (Okamura & Igarashi, 2010)), a pop-up book is a type of book where a single sheet of paper can be folded to create two or three-dimensional shapes that emerge when the book is opened. (Nancy & Rhonda, 2012) describe pop-up books as books that incorporate interactive motion using paper mechanisms such as folding, sliding, inserting, and rotating. Pop-ups are attractive paper art forms that create three-dimensional structures when opened and return to two-dimensional form when closed (Lizuka, Endo, Mitani, kanamori, & Fukui, 2011). Pop-up books not only produce three-dimensional shapes but also add motion, creating an enjoyable reading experience (Villanueva, et al., 2015). Pop-up books maintain the format of traditional books, but they contain elements that can move and change shape when opened.

Pop-up books, as described by (Bluemel dan taylor 2012), allow for movements using paper as the primary material for folding, rolling, shaping, patterning, and twisting. Pop-up books are media in the form of books, containing elements that can move when opened, resulting in dimensional changes. Pop-up books are versatile media suitable for individuals of all ages, as stated by (Dyk & Cooper-Hewitt, 2011): "For nearly 800 years, hinged, movable books have delighted and captivated readers and non-readers alike, young and old." Therefore, pop-up books can be used at all educational levels. Pop-up books can be highly beneficial for eighth-grade students in learning solid geometry concepts. Solid geometry is one of the topics in the learning process that requires visual aids for shape visualization. Pop-up books are ideal for teaching this topic. Using pop-up books in education can help students think critically and creatively, enabling them to find solutions

independently. The content that can be incorporated into pop-up books includes surface area and volume of three-dimensional solids (Johnson, R. B., & Miles, M. S., 2018).

The use of pop-up books in middle school education has evolved beyond merely exploiting their three-dimensional features. Various teaching approaches are being applied to maximize their utility. For example, (Dzulhikmah, 2017) developed a pop-up book instructional medium using a scientific approach for teaching triangle concepts to middle school students. However, this research did not focus on improving mathematical skills specifically. Thus, the researcher intends to develop a pop-up book instructional medium that not only enhances student motivation to learn but also aims to improve students' mathematical communication skills. The pop-up book instructional medium that the researcher will develop will be based on an investigative approach, encompassing the content and exercises presented through an investigative approach. This approach will guide students through each step of using the pop-up book, making it easier for them to understand the material.

The mathematical investigation approach is an approach that encourages students to engage in activities, collect data, examine patterns, make and test conjectures, and potentially arrive at generalizations (Bastow, Hughes, Kissane, & Randall, 1984). The pop-up book will contain various student activities, ranging from material exploration to problem-solving exercises using an investigative approach. Therefore, the pop-up book will enable students to understand the material more easily, with guidance at each step, encouraging active participation in experiments, data collection, problem-solving, and effective communication of problem-solving outcomes.

The investigative approach requires students to be more active in solving a problem. According to (Setiawan, 2006), the steps of the mathematical investigative approach are as follows: (1) understanding the problem; (2) solving the problem; (3) answering and communicating. These steps will be incorporated into the pop-up book that will be created. Starting from the beginning of the material, students will be guided to identify problems on their own. Subsequently, learners will be directed to solve the problems, and finally, students will be guided to communicate the problem-solving process. This way, students can enhance their mathematical communication skills using the mathematical investigative approach.

The foundation of this research is the development of a pop-up book instructional medium based on the investigative approach. This approach will be integrated into the pop-up book instructional medium. The technique for using the pop-up book in the classroom involves dividing students into three groups, with each group receiving one pop-up book based on the investigative approach for use in the learning process, following the teacher's instructions. The development of a pop-up book instructional medium based on the investigative approach has also been conducted by (Khusna, 2020), achieving highly valid and practical results with 100% student response and high effectiveness with an average student score of 90. Other research on the development of pop-up book instructional media has been carried out by (Luthfi & Suparman, 2019), which found that the pop-up book design was highly valid and practical, with an average score above 90%, and effective, with an average score above 80%.

2. METHOD

The research method to be used is the Research and Development (R&D) method. The R&D research design is employed to produce new products (Sugiyono, 2017). In this research, the researcher aims to develop a pop-up book instructional medium based on the investigative approach, hence the use of this method. The development model to be used is the 4-D development model, consisting of four stages: Define, Design, Develop, and Disseminate (Trianto, 2009). The subjects in this research are 8th-grade students, and the research object is the pop-up book instructional medium based on the investigative approach with the content of plane-faced solid figures. The research instruments used are:

1. Media validation sheet
2. Media practicability sheet
3. Mathematical communication skills test

Data collection involved pre-tests and post-tests to measure the improvement in students' mathematical communication skills. The pre-test was conducted before the intervention using the pop-up book, and the post-test was conducted afterward. The student scores obtained are then calculated using the effect size formula. Effect size is used to measure the magnitude of the influence of one factor on another, providing a quantitative measure of the impact of the pop-up book on students' mathematical communication skills.

The instruments and products were validated through expert reviews. The validation process involved feedback from educational media experts and mathematics educators to ensure content accuracy, appropriateness, and usability of the pop-up book.

3. RESULT AND DISCUSSION

The results and discussion in this study are as follows:

A. Development Process of Investigative Approach-Based Pop-Up Book Media

a. Define Stage

The Define stage aims to define every requirement in developing the product to meet the needs of the users. This stage involves analyzing the development needs and defining the product development requirements. The Define stage includes activities such as interviews with teachers and students, curriculum analysis, learning media requirements, software specifications, and student character analysis.

1) Interviews

Semi-structured interviews were conducted with mathematics teachers and eighth-grade students. The purpose of these interviews was to determine the students' needs to achieve the learning objectives. The interviews covered aspects such as students' interests and abilities, teaching methods used in the learning process, and the media employed in teaching.

Based on the information gathered from the interviews conducted by the researcher, it was found that students had a relatively low interest in learning mathematics, and they perceived mathematics as a difficult subject. There was a significant disparity in students' mathematical problem-solving abilities, with some understanding the material and others struggling with it. This was evident from the preliminary study conducted by providing mathematical problem-solving tasks that assessed mathematical communication skills. Most educators primarily used conventional teaching methods, such as lectures. The media used in teaching included mathematics textbooks, and there was an attempt to introduce instructional videos, but not all students had access to the necessary smartphones to view these videos.

2) Curriculum Analysis

Curriculum analysis was conducted to understand the curriculum used in the school so that the researcher could align the development with it. The purpose was to identify the competencies that could be incorporated into the learning media. The analysis examined the current curriculum to determine the competencies that could be applied in the development of the learning media.

The results of the curriculum analysis indicated that SMPN 1 Kadipaten used the 2013 curriculum. After identifying the curriculum used by the school, the researcher proceeded to analyze the basic competencies and competency achievement indicators as a reference for developing the media. The basic competencies and competency achievement indicators for the content on plane-faced solid figures can be seen in Table 1. Basic Competencies and Indicators of Competency Achievement

Table 1. Basic Competencies and Indicators of Competency Achievement

Basic Competencies	Indicators of Competency Achievement
1.9 Differentiate and determine the surface area and volume of flat-sided spaces (cubes, beams, prisms and pyramids). 1.10 Solve problems related to the surface area and volume of flat-sided spaces (cubes, beams, prisms, and pyramids), and their combinations.	1. Students are able to differentiate flat-sided spaces. 2. Students have the ability to determine the nets of flat-sided spaces. 3. Students can understand the surface area of flat-sided spaces. 4. Students can recognize the volume of a flat-sided room. 5. Students are able to determine the volume of flat-sided spaces. 6. Students have the ability to solve problems related to flat-sided spaces.

3) Software Specifications

The software used to design this media is Adobe Illustrator 2022. The reason for choosing Adobe Illustrator 2022 is that this software is highly proficient in creating vectors in images and can transform images into vectors very effectively.

b. Design Stage

The design phase aims to create the initial design of the product to be developed. The design steps are as follows:

1) Test Development

During test development, a validation questionnaire will be created and submitted to subject matter experts and media experts to assess the feasibility of the pop-up book media based on the investigative approach. Additionally, a questionnaire for student responses to the investigative pop-up book media will be generated.

2) Material Design

The material used in this media is based on the investigative approach, allowing students to follow instructions and discover various problems and solutions on their own. The source material used is derived from the Ministry of Education and Culture's mathematics textbook for eighth grade. The specific material used is flat-faced space figures.

3) Flowchart Creation

Creating a flowchart or a sequence of activities is an initial step in the development of the investigative-based pop-up book media. The flowchart for creating the investigative pop-up book media is depicted in Figure 1.

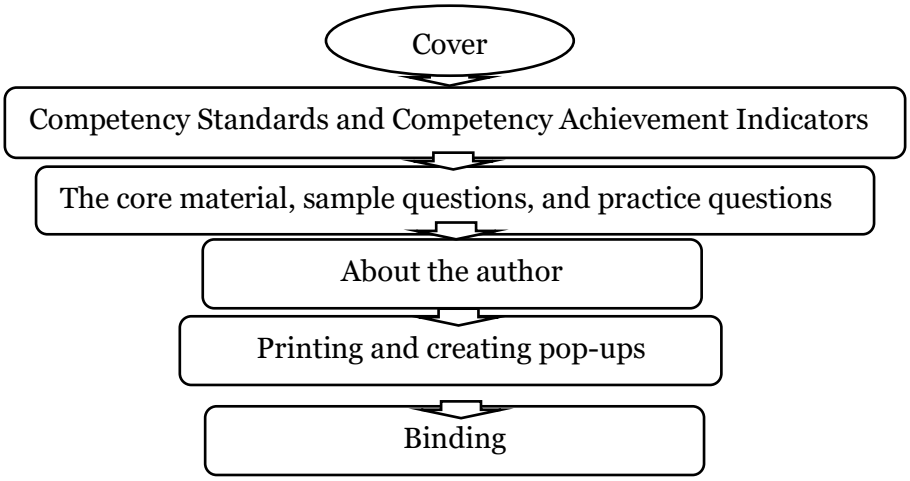


Figure 1. Flowchart

4) Storyboard Creation

The storyboard contains a description of the design layout that will be worked on, starting from the cover to the final section, which will then be consulted with media experts.

5) Image Creation

The creation of images is done using Adobe Illustrator 2022 software. Image creation begins by creating artboards in Adobe Illustrator, followed by drawing vectors. For images from other sources, they are converted into vectors using image tracing, and then specific parts can be edited and combined with the vectors that have been created. At this stage, ensure that all elements are vectors so that the final result has very good image quality. The steps for creating images using Adobe Illustrator are shown in Figure 2.

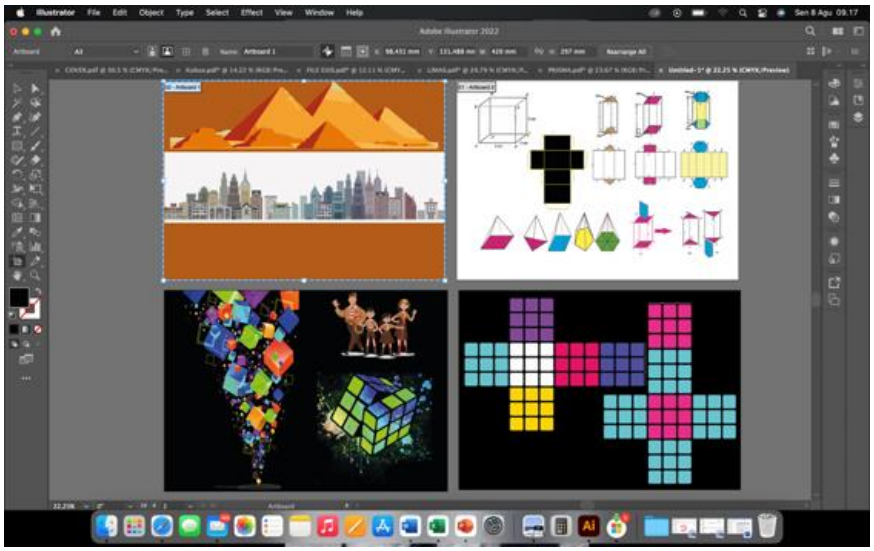


Figure 2. Images Creation

6) Creating Background Images

Once all the images have been created, the next step is to create background images. The background should be tailored to the theme of each subsection of the flat-faced solid figures material that will be created. Below is the background for the cube material as shown in Figure 3.

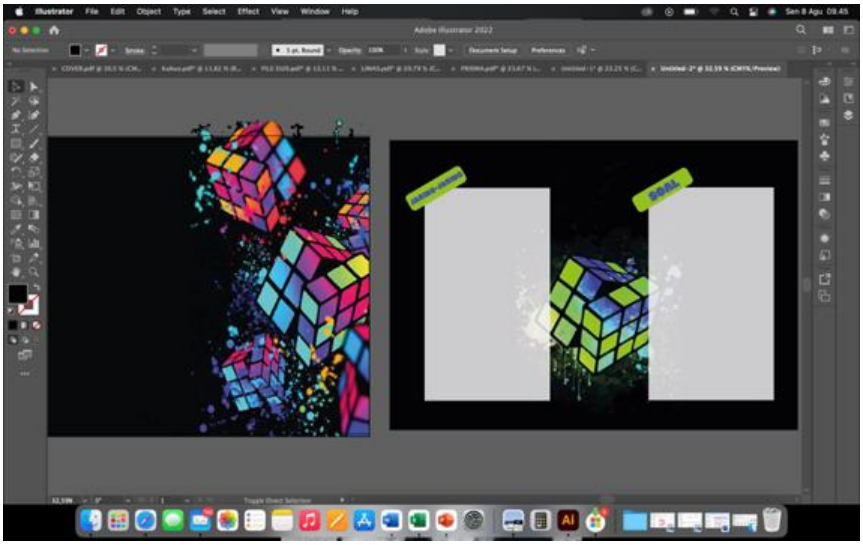


Figure 3. Background for the Cube Material

7) User Interface Design

User interface design is the stage of combining backgrounds, images, and content. The user interface design for the investigative approach-based pop-up book media is as follows:

a) Cover Page

On this page, there is information about the book title, content, media target, author's name, and institute.

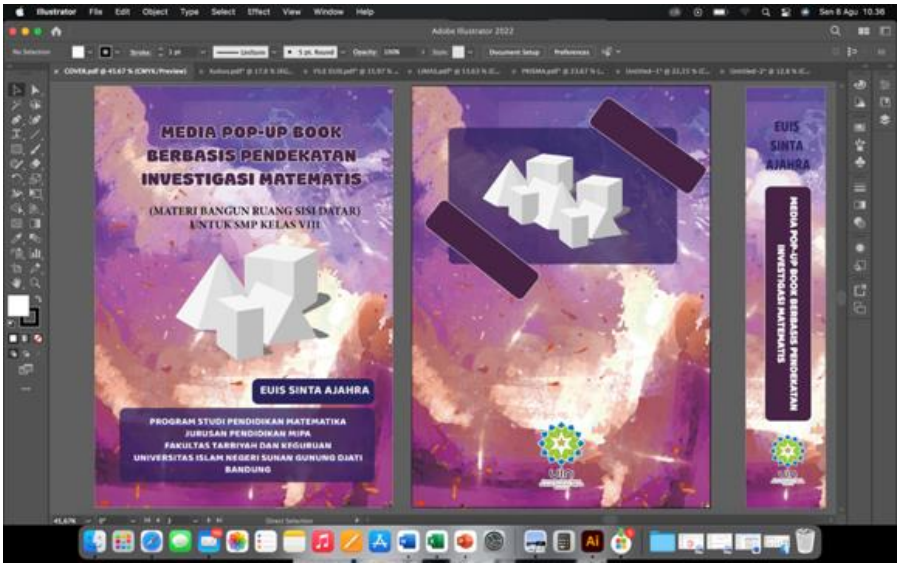


Figure 4. Cover Page

b) Competency-Based Page, Competency Achievement Indicators, and Concept Map

On this page, there is information about the competency base, competency achievement indicators, and a concept map. This information is provided so that students can understand what needs to be achieved in this learning session. Below is the competency-based page, competency achievement indicators, and concept map as shown in Figure 5.

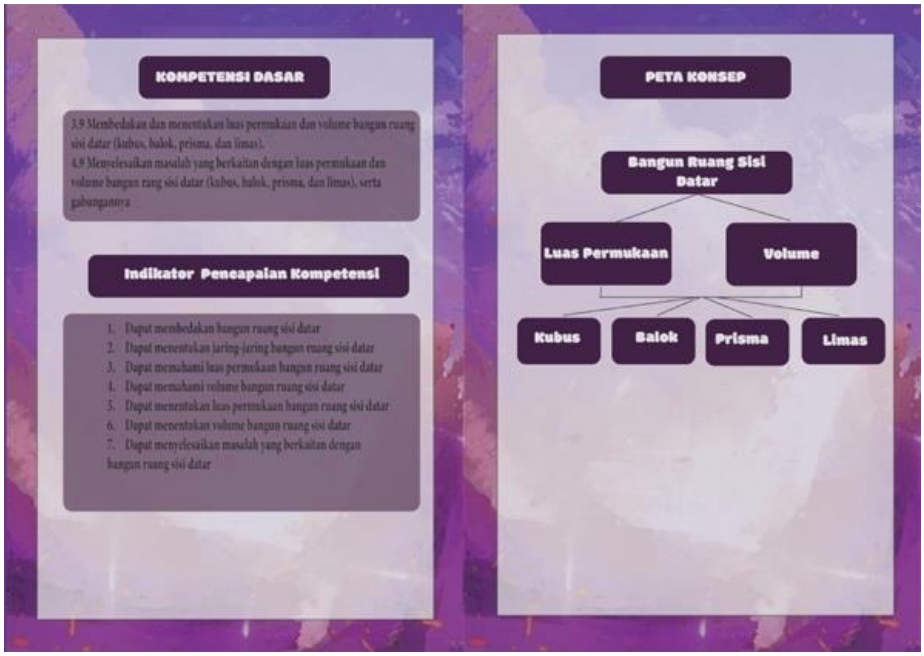


Figure 5. Competency-Based Page, Competency Achievement Indicators, and Concept Map

c) Material Page

On the material page, there is material related to flat-faced solid figures presented using the investigative approach. Below is the material page as shown in Figure 6.

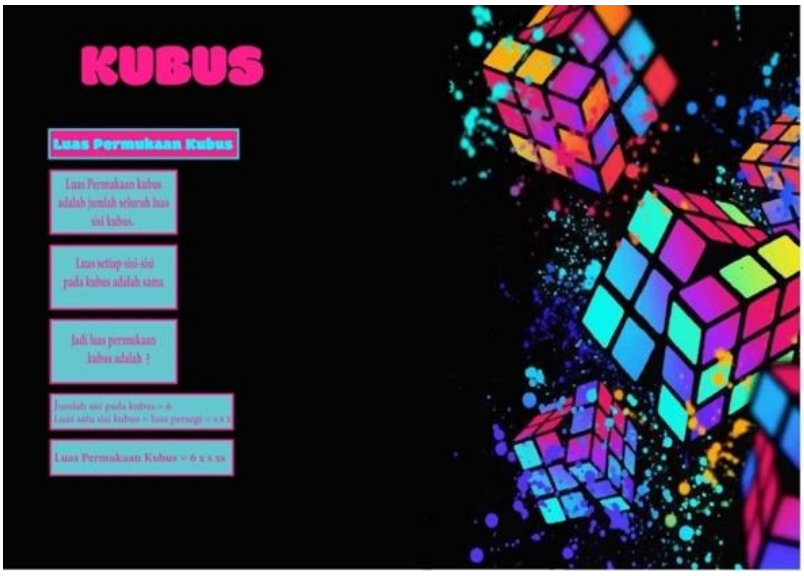


Figure 6. Material Page

d) Game Page and Author Information

On this page, there are instructions for playing a game led by the teacher, and there is also information about the author. Below is the game page and author information as shown in Figure 7.

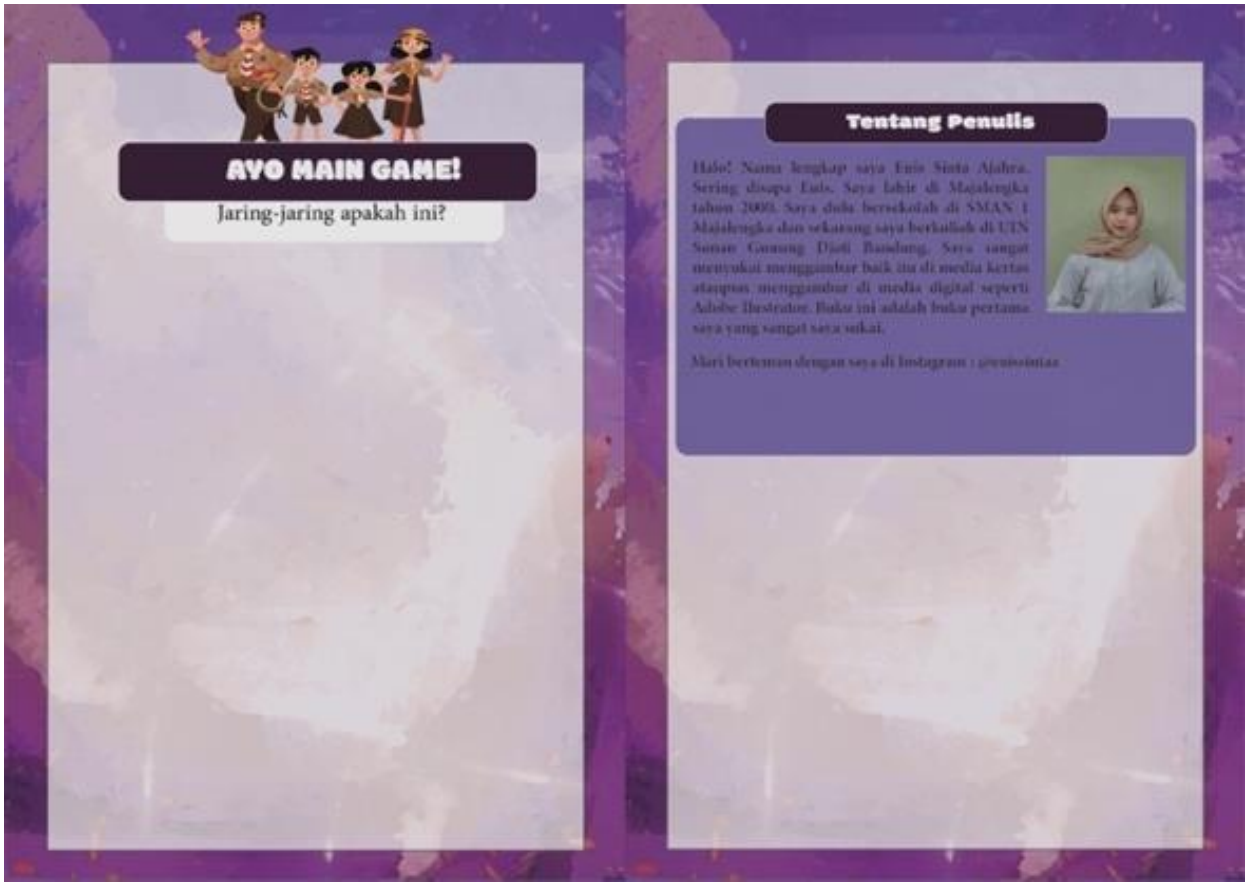


Figure 7. Game Page and Author Information

8) Printing Images, Backgrounds, and Material

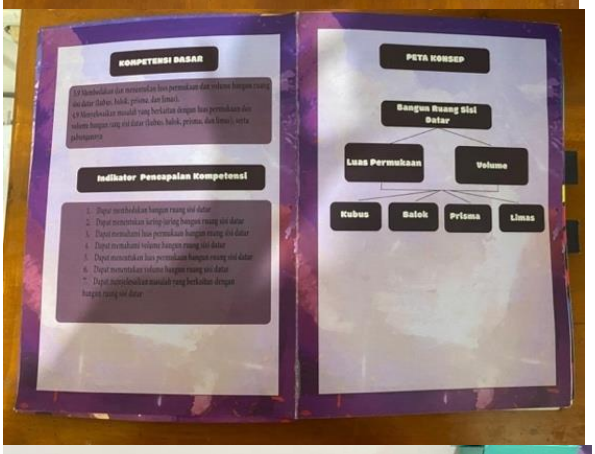
After all the designs have been completed, the designs are printed on A3-sized paper in landscape format. In the creation of a pop-up book, there needs to be a mechanism space between each sheet for the pop-up book mechanism to function. After everything is printed, it is folded in half, and the ends of the paper are glued together. The final step is to print the cover design with hardcover binding specifications.

9) Pop-Up Book Creation

Below are scenes from the pop-up book as shown in Table 2.

Table 2. *Scene Pop-Up Book*

Display	Description

	Cover page
	Competency-Based Page, Competency Achievement Indicators, and Concept Map Page.
	Cube Material Sheet along with 3-dimensional pop-up elements of cube illustration.
	

Rectangular Prism Material Sheet along with 3-dimensional pop-up elements of rectangular prism illustration.

Prism Material Sheet along with 3-dimensional pop-up elements of prism illustration.

Pyramid Material Sheet along with 3-dimensional pop-up elements of pyramid illustration.

c. Develop Stage

In the develop stage, the focus is on product development and testing. The result of this stage is the validation of the pop-up book media based on the investigative approach.

a) Expert Validation

The pop-up book media is first assessed for its validity by subject matter experts and media experts. This step ensures that the content is accurate and the design is effective for educational purposes.

b) Small-scale Testing

Small-scale testing of the pop-up book media was conducted in class VIII B. This small-scale testing involved 10 students who engaged in learning activities using the pop-up book media based on the investigative approach. After the learning process, the students were provided with a practicality questionnaire to evaluate the usability of the pop-up book media.

c) Large-scale Testing

After completing the small-scale testing, large-scale testing was carried out, involving a total of 29 students from class VIII D. These students had previously participated in learning using the pop-up book media based on the investigative approach. Upon completing the learning activities, the students were given a practicality questionnaire to assess their opinions on the usability of the pop-up book media based on the investigative approach.

d. Dissemination Stage

The final outcome of this development process is the creation of the pop-up book media based on the investigative approach, which has undergone various stages of validation and testing. In the final stage, the pop-up book media based on the investigative approach for mathematics is disseminated. Due to various limitations, this dissemination is conducted on a limited scale, with the researcher distributing it to a school other than the research site, specifically MTsN 7 Majalengka.

B. Validity of the Pop-Up Book Media Based on the Investigative Approach

The assessment of the validity of the pop-up book media based on the investigative approach was conducted by experts in media and subject matter.

1) Assessment by Media Expert Validators

The pop-up book media based on the investigative approach was validated by two experts in media. The results of the validation are presented in Table 3.

Table 3. The Results of the Validation

Aspect	Indicator	Score	
		Validator 1	Validator 2
Ease and Practicality	Ease of pop-up book media.	80%	65%
	Practicality, flexibility, and durability	85%	80%
Appearance Assessment	Coloring	93%	100%
	Graphics	85%	85%
	Design	100%	90%

	Overall appearance	84%	80%
Language Assessment	Word or language selection	80%	96%
Average Score		86%	85%
Criteria		85,5% Very Valid	

Based on Table 3, the validation results by media experts obtained an average score of 85.5%, falling under the "Very Valid" category.

2) Assessment by Content Expert Validator

The pop-up book media based on the investigative approach was validated by a content expert. Here are the validation results in Table 4.

Table 4. Content Expert Validation Results

Aspect	Indicator	Score
Content Suitability	Alignment with Competency Standards	86%
	Quality of Content	88%
	Presentation	76%
	Ease of Use and Attractiveness	64%
Language Assessment	Clarity	70%
	Communicative and Interactive	70%
	Adaptation to Student Development Level	60%
	Use of Terms, Symbols, and Icons	60%
	Average Score	72%
	Criteria	Valid

The validation results by the content expert yielded an average score of 72%, falling under the "Valid" category.

C. Practicability Analysis

The practicability analysis aims to determine the practicality of the pop-up book media based on the investigative approach being developed. To assess its practicality, questionnaires were given to students who had undergone the learning process using the pop-up book media. Here are the results:

1) Small-scale Practicability Testing

The results of the small-scale practicability questionnaire, conducted with 10 students from class VIII B, are presented in Table 5.

Table 5. Small-scale Practicability Score

No.	Aspect	Score	Criteria
1.	Appearance	92%	Very Practical
2.	Presentation of Material	85%	Very Practical
3.	Language	85%	Very Practical
4.	Ease and Practicality	88%	Very Practical

Average Score	87%	Very Practical

Based on Table 5, the average practicality questionnaire score is 87%, with a "Very Practical" criteria. This indicates that the pop-up book media based on the investigative approach is highly practical and can proceed to large-scale testing.

2) Large-scale Practicability Testing

The results of the large-scale practicability questionnaire, conducted with 29 students from class VIII D, are presented in Table 6.

Table 6. Large-scale Practicability Score

No.	Aspect	Score	Criteria
1.	Appearance	90%	Very Practical
2.	Presentation of Material	86%	Very Practical
3.	Language	88%	Very Practical
4.	Ease and Practicality	89%	Very Practical
Average Score		88%	Very Practical

Based on the table, the average practicability questionnaire score is 88%, with a "Very Practical" criteria. This indicates that the pop-up book media based on the investigative approach is highly practical and suitable for learning.

D. Effectiveness Analysis

The effectiveness analysis of using the investigative approach-based pop-up book media is based on student learning outcomes, which include a pretest or initial proficiency test at the beginning of the learning process before using the investigative approach-based pop-up book media and a posttest, which is a proficiency test at the end of the learning process after the use of the investigative approach-based pop-up book media. This test was administered to students who participated in the learning process using the investigative approach-based pop-up book media. Below are the results of the effectiveness test for the development of the investigative approach-based pop-up book media.

Table 7. Summary of Pretest and Posttest

	n	Mean	SD
Pretest	29	4,17241379	2,75251788
Posttest	29	15,7586207	3,61203516

Table 8. Effect Size Results

$M_2 - M_1$	SD_{Polled}	d	Category
11,586	3,211	3,608	High

Based on Table 8, the effectiveness results for the pop-up book media achieved an effect size of 3.608, categorized as "High." This indicates that the investigative approach-based pop-up book media is effective in improving students' mathematical communication skills.

E. Improvement in Middle School Students' Mathematical Communication Skills

The improvement in middle school students' mathematical communication skills can be assessed through the data obtained from the students' mathematical communication proficiency tests. The data used in this study includes pretest and posttest data, which are then converted into the N-Gain formula.

Data on the average improvement (N-Gain) related to mathematical communication proficiency is presented in Table 9.

Table 9. Average Improvement (N-Gain) Summary

Category	Skor
Pretest	4.17
Posttest	15.75
Average Difference	11.58
Class N-Gain (100%)	0.74
Criteria	High

Based on the table, it is evident that the average N-Gain score increased by 0.74, categorized as "High." This indicates a significant improvement in mathematical communication skills. This finding aligns with previous studies indicating that visual aids can substantially enhance students' understanding of mathematical concepts (Smith & Brown, 2015).

The use of pop-up books as a visual learning medium has been shown to engage students more effectively than traditional methods (Johnson & Miles, 2018). These books provide interactive and tangible experiences that help students visualize and understand complex geometric shapes and relationships, which are often challenging to grasp through conventional textbooks alone. By manipulating the pop-up elements, students can better comprehend the spatial properties and dimensions of three-dimensional solids.

Furthermore, the investigative approach integrated into the pop-up books encourages critical thinking and problem-solving skills. According to research by (Lee and Anderson, 2019), incorporating investigative tasks in mathematics instruction promotes deeper understanding and retention of mathematical concepts. The significant increase in the N-Gain score in this study supports this claim, suggesting that students who engage in investigative activities with visual aids, like pop-up books, can improve their mathematical communication skills more effectively.

The high N-Gain score also reflects the practicality and effectiveness of the pop-up book as a teaching medium. Its ability to present abstract concepts in a concrete and interactive manner makes it a valuable tool in the mathematics classroom. Additionally, the simplicity and direct usability of pop-up books mean they can be easily integrated into existing curricula without the need for extensive additional resources.

The results of this study demonstrate the effectiveness of investigative-based pop-up book media in enhancing junior high school students' mathematical communication skills. The findings are consistent with existing literature that emphasizes the importance of visual aids and investigative approaches in improving students' understanding and communication of mathematical concepts.

4. CONCLUSION

The development of investigative approach-based pop-up book media was analyzed descriptively using the R&D method with the 4D model: define, design, develop, and disseminate. All stages have been completed, resulting in a usable product. The validity of the investigative approach-based pop-up book media in terms of media aspects received a score of 85.5%, falling under the "Very Valid" category. In terms of content aspects, it received a score of 72%, categorized as "Valid." This means that both in terms of content and media, the criteria for validity have been met, and the media is suitable for use.

The practicability of the investigative approach-based pop-up book media in small-scale testing received a score of 87%, categorized as "Very Practical." Similarly, the results in large-scale testing received a score of 88%, also categorized as "Very Practical." Therefore, the investigative approach-

based pop-up book media is highly practical. The effectiveness of the media was determined through an analysis of pretest and posttest scores using the effect size. The effect size obtained was 3.608, categorized as "High," indicating that the investigative approach-based pop-up book media is highly effective.

There was an improvement in middle school students' mathematical communication skills after using the pop-up book, with an N-Gain result of 0.74, categorized as "High." Therefore, the investigative approach-based pop-up book media can enhance students' mathematical communication skills.

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