

Integrated Non-Digital Media Innovation 'Space Capsule' to Train Spatial Visualization Skills in Solid Geometry for Students

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Article received: 31-12-2025, revision: 17-01-2026, published: 31-01-2026

Abstrak

Tujuan penelitian ini menghasilkan media pembelajaran non-digital terintegrasi bernama "Kapsul Ruang" untuk melatih kemampuan visualisasi spasial materi bangun ruang siswa SMP. Studi ini dirancang menggunakan pendekatan model 4D, yang mencakup fase Define, Design, Develop, dan Disseminate yang melibatkan validator ahli materi dan media, serta siswa SMP sebagai subjek uji coba melalui tahapan one-to-one, small group, dan field test. Informasi dikumpulkan serta dievaluasi berdasarkan standar validitas, kegunaan praktis, dan dampak efektif dari bahan ajar non-digital yang sedang dalam proses pembuatan. Media non digital terbukti memiliki tingkat kevalidan 85% dengan kategori sangat valid, kepraktisan tinggi dengan persentase 89,3%, dan efektif meningkatkan pemahaman konsep geometri tiga dimensi, terutama bagi sekolah dengan keterbatasan akses teknologi digital. Media non digital ini berimplikasi bagi pembelajaran matematika sebagai sepaket media pembelajaran dengan integrasi pendekatan visual, manipulatif, dan game-based learning sehingga yang memberikan alternatif solusi praktis yang responsif.

Kata Kunci: Pembelajaran Matematika; Media Non-Digital; Bangun Ruang; Visualisasi Spasial.

Abstract

The purpose of this study is to produce an integrated non-digital learning media called "Space Capsule" to train the spatial visualization ability of junior high school students' spatial geometry material. The study was crafted using the 4D development framework, which includes the stages of Define, Design, Develop, and Disseminate used by involving expert validators of material and media, as well as junior high school students as trial subjects through one-to-one, small group, and field test stages. Information was gathered and evaluated based on the standards of validity, practicality, and effectiveness for the non-digital media currently in development. Non-digital media is proven to have a validity level of 85% with a very valid category, high practicality with a percentage of 89.3%, and is effective in increasing the understanding of three-dimensional geometry concepts, especially for schools with limited access to digital technology. This non-digital media has implications for mathematics learning as a package of learning media with an integration of visual, manipulative, and game-based learning approaches, thus providing alternative responsive practical solutions.

Keywords: Mathematics Learning; Non-Digital Media; Solid Geometry; Spatial Visualization.

I. INTRODUCTION

Spatial visualization is a fundamental cognitive skill essential for learning mathematics, particularly three-dimensional geometry. Spatial abilities encompass the cognitive functions required to interpret and work with information related to space and form. These skills are fundamental in science, technology, engineering, and mathematics (STEM), as they allow learners to mentally rotate objects, handle 3D representations, and convert flat, two-dimensional diagrams into three-dimensional mental constructs (Carbonell-Carrera et al., 2021). Empirical evidence indicates that numerous learners struggle with grasping three-dimensional geometric concepts and shifting between flat and volumetric representations. The capacity to form precise mental pictures of spatial forms, along with a robust three-dimensional visual-spatial comprehension, constitutes key determinants affecting an individual's proficiency in mastering spatial geometry (Lisnani, et al. 2025).

Numerous prior investigations have explored the role of spatial visualization in the context of geometric figures. These studies highlight that spatial visualization ability provides a distinct and additional contribution to an individual's capacity for solving mathematical word problems (Likhanov et al., 2024; Commodari et al., 2024; Arıkan & Çetin, 2024). This research investigates the application of technological tools and educational resources to enhance learners' spatial reasoning. It specifically examines the effectiveness of teacher-guided demonstrations using three-dimensional models, complemented by both static and

animated two-dimensional anatomical charts. (Feng et al., 2025), The use of augmented reality (AR) showed that learning with 3D representations compared to 2D representations resulted in a higher cognitive load and better knowledge of the spatial relations of components, where higher mental rotation abilities were found to be more beneficial for learning with 3D visualizations (Lisnani, et al. 2025) Schoenherr et al., 2024; Krüger et al., 2022), the use of software, blocks, strips, tiles, and other resources to teach students a variety of mathematical concepts and skills (Ochugboju & Díez-palomar, 2025).

These findings underscore the importance of integrating spatial visualization skill development and digital technology into spatial geometry learning. However, there is a significant gap in implementation in schools with limited access to technology. Many schools, especially in resource-limited areas, lack adequate technological infrastructure to consistently implement digital-based solutions.

This situation creates an urgent need for the development of non-digital learning media that can still provide a quality spatial learning experience. Furthermore, previous research tends to focus on just one or two learning approaches, while no research has comprehensively integrated multiple approaches into a single physical learning medium, encompassing visual, manipulative, conceptual, and game-based learning simultaneously.

Based on the research gap, the researcher took the initiative to design an integrated non-digital learning media named "Space Capsule". Space Capsule is

an integrated non-digital learning media specifically designed to improve the spatial visualization ability and mastery of solid geometry for junior high school students. This media combines five complementary interactive components: TV "Scroll of Shapes" for the introduction of basic concepts through dynamic visualization, Concept Map "The Shape Spectrum" for the classification and organization of knowledge, Book "Folding Geometry" for in-depth exploration of seven spatial geometry (cube, cuboid, prism, pyramid, cone, cylinder, and sphere), Magnet "Mageo" for interactive manipulation and concept matching, and Monopoly "Mathpology" for strengthening understanding through educational games. The integration of these various learning approaches is expected to facilitate comprehensive conceptual understanding while increasing student engagement and motivation, while providing a practical alternative that does not depend on the availability of digital technology but remains effective in developing students' spatial visualization abilities.

This research aims to produce a non-digital learning media "Space Capsule" that meets the criteria of being valid, practical, and effective in improving the spatial visualization abilities and mastery of solid geometry of junior high school students through a 4D model development approach (Define, Design, Develop, Disseminate).

II. METHOD

This research is development research that uses a 4D model which consists of four

main stages, namely Define, Design, Develop, and Disseminate (Nusantara et al., 2023). The define stage in this research includes analysis of student needs through questionnaires, curriculum analysis to ensure suitability with basic competencies, and analysis of solid geometry. The design stage includes designing the Space Capsule media components which include the "Scroll of Shapes" TV, "The Shape Spectrum" Concept Map, "Folding Geometry" Book, "Mageo" Magnet, and "Mathpology" Monopoly along with the necessary research instruments. The develop stage involves the process of prototyping, expert validation, revision, and a series of gradual trials to evaluate the practicality and effectiveness of the media. Meanwhile, the disseminate stage in this research is limited to disseminating research results through journal publications and scientific presentations.

Validation includes several assessment aspects, namely the suitability of the material with the Basic Competencies and Competency Achievement Indicators of the Junior High School curriculum, the accuracy of mathematical concepts and formulas, the systematic presentation of the material from simple to complex, the completeness of the material covering seven geometric shapes, the quality of the evaluation questions covering various cognitive levels, and the suitability of the material to the characteristics of Junior High School students. The material expert validator provided several suggestions for improvement, especially on the explanation of the concept of the diagonal of space which needs to be clarified with

additional illustrations, refining the level of difficulty of the questions on the "Mathpology" Monopoly cards to make them more varied and challenging, and adding examples of applicable questions that are contextual to students' daily lives.

The subjects of this study were junior high school students studying spatial geometry, involving three different groups according to the trial stages. The first group for one-to-one testing consisted of three students to obtain initial feedback on the media's readability and ease of use. The second group for small group testing involved nine students with heterogeneous characteristics to evaluate the media's practicality in small groups. This stepwise approach aligns with the principles of formative evaluation in the development of learning media, which emphasizes the importance of tiered trials (Waruwu, 2024). The third group for the field test involved a full class of students to measure the media's effectiveness in a real-life learning context. The study also involved expert validators, consisting of mathematics subject matter experts and learning media experts, to ensure the content and construct validity of the developed media (Widoyoko, 2021).

The data collection technique used questionnaires and tests. The validity questionnaire was divided into two parts: a questionnaire for questions with 20 statement items and a questionnaire for media with 15 items, as shown in Table 1 and Table 2.

The validity indicators for the questions are as shown in Table 1.

Table 1.
Validation Indicators for the "Space Capsule" Learning Media

No	Indicator	Total of Statement Items
1.	Content Eligibility	4
2.	Question Construction	6
3.	Learning Appropriateness	5
	Total	15

Meanwhile, the validity indicators for the media are as in Table 2.

Table 2.
Validation Indicators for the "Space Capsule" Question

No	Indicator	Total of Statement Items
1.	Content/Material Suitability	6
2.	Design Feasibility	5
3.	Feasibility of Use	4
4.	Learning Feasibility	5
	Total	20

Expert validation is an essential stage to ensure the quality and suitability of learning products. (Maydiantoro, 2021). The student test questions were designed to measure mastery of solid geometry and spatial visualization skills after using the media. A media satisfaction questionnaire was used to measure the level of satisfaction of students and expert validators regarding the feasibility, practicality, and effectiveness of the media in facilitating spatial geometry learning.

Data obtained from the research instruments were analyzed using quantitative descriptive analysis techniques to describe the validity, practicality, and effectiveness of the developed media. Data from expert validation and satisfaction questionnaires were converted into scores using a Likert scale, then the percentage of achievement was calculated to determine the media's feasibility category based on

predetermined interpretation criteria (Widoyoko, 2021). Data analysis was carried out in stages according to the trial phase, where the results of each phase became the basis for making improvements and refinements to the media before continuing to the next phase with indicators of validity, practicality, and effectiveness of the media being developed.

Table 3.
Interpretation Criteria for Percentage Validity, Practicality, and Effectiveness

Percentage of Achievement	Category
80% < N ≤ 100%	Very Valid/Very Practical/Very Effective
60% < N ≤ 80%	Valid/Practical/Effective
40% < N ≤ 60%	Quite Valid/Quite Practical/Quite Effective
20% < N ≤ 40%	Less Valid/Less Practical/Less Effective
0% < N ≤ 20%	Invalid/Impractical/Ineffective

III. RESULT AND DISCUSSION

A. Result

1) Define Stage

At this stage, a questionnaire was given to analyze the learning media needs for the material of spatial figures for junior high school students. The results obtained were that 87.5% of students stated that they had difficulty in understanding the material of spatial figures, especially in the aspects of imagining three-dimensional shapes from two-dimensional representations, identifying elements of spatial figures such as plane diagonals and space diagonals, understanding nets of spatial figures, and calculating volume and surface area. The biggest difficulty faced by students was in visualizing abstract concepts of spatial

figures into concrete images that could be understood.

A total of 92.3% of students stated they needed more interactive and concrete learning media to help them understand spatial concepts. Seventy-eight percent of students felt that learning using textbooks alone was uninteresting and difficult to understand because they only presented two-dimensional images that could not be manipulated. Students wanted media they could touch, rotate, and explore directly to build a deeper understanding of concepts. This data shows a gap between conventional learning methods, which tend to be abstract, and students' need for more visual and manipulative learning experiences.

The analysis results show that the material on geometric shapes covers seven types of shapes: cubes, cuboids, prisms, pyramids, cones, cylinders, and spheres, which students must master. Each geometric shape has different characteristics, elements, and formulas for volume and surface area, which require a strong conceptual understanding. Students grasp concepts more easily when they can see, touch, and manipulate the learning objects directly.

2) Design Stage

This media is designed in the form of a miniature cube-shaped capsule with dimensions of 64 cm × 44 cm × 30 cm that can be opened and closed to access the five components inside. The capsule design uses thick cardboard material that is strong but lightweight, with a capsule door that can be opened to the side using a simple hinge system. The first component is the

"Scroll of Shapes" TV which is designed in the form of a miniature television with a paper roll system using two pipes as a rolling axis. This component has a rectangular screen with a manual rotating system using a pipe as a handle. Learning materials about the definition of geometric shapes, main characteristics, elements of geometric shapes, and various geometric shapes are printed on a roll of paper approximately 2 meters long that can be scrolled back and forth.

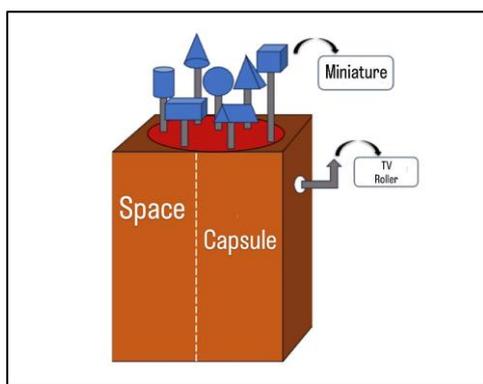


Figure 1. Design of the "Space Capsule" non-digital learning media in closed condition.

Figure 1. Design of the "Space Capsule" non-digital learning media in closed condition, showing the external physical form of the capsule before use. The closed structure allows the learning components to be stored compactly and organized within a single container.

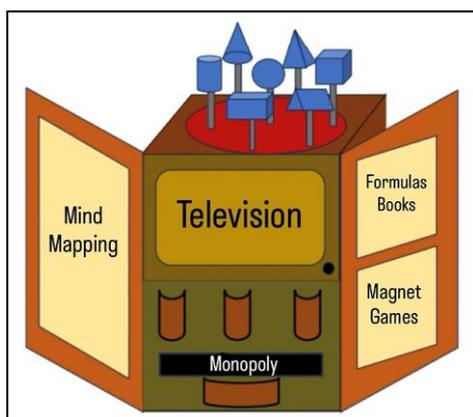


Figure 2. Design of the "Space Capsule" non-digital learning media in open condition.

Figure 2. Design of the "Space Capsule" non-digital learning media in open condition, illustrating access to the internal learning components, including concept maps, geometry folding books, manipulatives, and game-based materials used during learning activities.

Figures 1 and 2 demonstrate the operational mechanism of the Space Capsule learning media. The capsule is first presented in a closed condition for storage and organization, then opened during learning activities to allow students to access and manipulate the integrated solid geometry learning components.

The second component is the Concept Map "The Shape Spectrum" designed in the form of a 40 cm × 30 cm poster that displays the classification of geometric shapes systematically. The concept map divides geometric shapes into two large categories: regular geometric shapes consisting of regular polyhedrons and curved-sided geometric shapes, and irregular geometric shapes including natural, artificial, and organic shapes. The visual design uses a different color scheme for each category with attractive and easy-to-understand geometric shapes illustrations.

The third component is the "Folding Geometry" book, which consists of seven mini-books measuring 15 cm × 10 cm, each discussing a type of geometric figure in depth. Each book contains the definition of geometric figures, their special characteristics, their constituent elements, volume and surface area formulas, folding nets, and practical examples. The book is designed with a folding system that allows

students to explore geometric nets hands-on.

The fourth component is the "Mageo" Magnet, a three-dimensional geometric miniature made of thick cardboard with a magnet on the back. There are seven geometric miniatures in different colors that can be attached to the capsule door. On the capsule door are seven boxes containing the volume formulas for each geometric figure. Students are asked to match the geometric miniatures with the corresponding volume formulas, thus practicing understanding mathematical concepts and formulas. The fifth component is the "Mathpology" Monopoly, which is designed as an educational game in the form of a 60 cm x 40 cm monopoly board with a geometric theme. This game is equipped with two cube-shaped dice, four transparent geometric pawns, and three sets of green, orange, and pink question cards containing questions with varying levels of difficulty. The monopoly board is printed on a banner and attached to thick cardboard for strength and durability (see Figure 3).

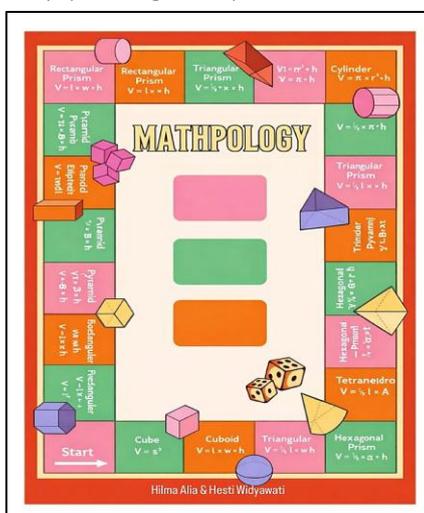


Figure 3. Components of the "Mathpology" Monopoly.

In addition to designing the media, validation and evaluation instruments were also developed at this stage, including a material expert validation sheet, a media expert validation sheet, test questions to measure student mastery of the material, and a questionnaire assessing satisfaction with the learning media. Each instrument was designed with clear and measurable assessment indicators using a Likert scale to facilitate data analysis.

3) Develop Stage

a) Expert Validation

After the "Space Capsule" media prototype was completed according to the design, the next stage was validation by experts to ensure its suitability before being tested on students. The validation results from learning material experts showed an average percentage of 89.2%, categorized as "very valid."

The average percentage of validity of the questions developed to measure students' mastery of the material reached 87.5% with a material feasibility category of "very good". The questions developed have met the criteria of content validity, construct validity, varying levels of difficulty, and adequate discriminating power to measure students' abilities in understanding the concept of geometric shapes and spatial visualization abilities. The results of the validation by learning media experts showed an average percentage of 91.7% with a "very valid" category.

The validation results for the learning media by three experts were 3.40, in the Very Valid category. Furthermore,

validation of the questions yielded a score of 74.44%, in the Valid category.

b) Product Trial

The one-to-one implementation process is carried out individually where each student uses the "Space Capsule" media in turns with the assistance of researchers as shown in Figure 4.



Figure 4. One-to-One Test Image.

Students were asked to explore each media component, from the "Scroll of Shapes" TV, Concept Maps, "Folding Geometry" Book, "Mageo" Magnets, to playing "Mathpology" Monopoly. Initial findings from the one-to-one test showed that in general, all three students gave a positive response to the developed media. Students stated that the media was very interesting, different from ordinary textbooks, and helped them understand the concept of geometric shapes more easily. However, several important inputs were obtained from students, including that the instructions for using the "Scroll of Shapes" TV needed to be clarified so that students were not confused about how to rotate the scroll, the text size in some parts of the "Folding Geometry" Book was too small so it was difficult to read, and the rules of the "Mathpology" Monopoly game needed to be explained in more detail at

the beginning of the game. Based on these inputs, the first stage of revision was carried out by adding clearer instructions for use for each component, increasing the font size in parts that were difficult to read, and creating a more systematic Monopoly game guide sheet.



Figure 5. Small Group Image.

After the first stage of revision, the "Space Capsule" media was piloted on a small group of nine students with heterogeneous characteristics (see Figure 5). The implementation process was carried out by dividing students into three groups, each group consisting of three people. Each group used the media in turns during one learning session with a duration of 2×40 minutes. Students explored each component of the media collaboratively, discussed in groups, and played Monopoly "Mathpology" together. The results of the satisfaction questionnaire completed by nine students showed an average percentage of 88.4% with the category "very satisfied". Aspects that were highly rated by students included the appeal of the media, ease of use, clarity of material, benefits for understanding concepts, and the desire to continue using the media in learning.

c) Field Test



Figure 6. Field Test Image.

The field test is the final stage of the trial, conducted in a full class of 32 students to measure the effectiveness of the media in a real learning context (see Figure 6). The learning process was carried out over three meetings with a total of 6 x 40 minutes. The first meeting focused on introducing the media and exploring the TV components "Scroll of Shapes" and Concept Maps. In the second meeting, students studied in depth through the "Folding Geometry" book and practiced with "Mageo" Magnets. The third meeting was filled with the Monopoly game "Mathpology" and learning evaluation through a material mastery test. The results of the material mastery test for spatial shapes showed that 84.4% of students achieved learning completion with scores above the set KKM. Significant improvements occurred in the aspects of spatial visualization abilities, understanding of the elements of geometric shapes, and the application of volume and surface area formulas in problem solving. The results of the student satisfaction questionnaire on the "Space Capsule" media showed an average percentage of 90.1% with the category of "very satisfied". Based on the

results of the test and questionnaire, the "Space Capsule" media is categorized as having a very high level of practicality with a percentage of 89.3% and very good effectiveness with a learning completion percentage of 84.4%, so this media is suitable and effective for use in learning geometric shapes at the junior high school level.

4) Dissemination Stage

The dissemination phase of this research was carried out in a limited manner due to time and scope constraints. The dissemination strategy included presenting the research results at a local mathematics education seminar forum, publishing research articles in scientific mathematics education journals, and providing outreach to junior high school mathematics teachers in the school environment where the research was conducted. Responses and feedback from the educational community demonstrated a high level of appreciation for the integrated non-digital media innovation developed. Several mathematics teachers expressed interest in adopting the "Space Capsule" media in their classrooms and requested more detailed media development guidance. This shows that the media developed has the potential to be replicated and disseminated more widely in other schools, especially those with limited access to digital learning technology.

B. Discussion

The "Space Capsule" media makes a substantial contribution to the development of spatial visualization skills through a multi-representational approach.

Physical manipulation of three-dimensional spatial structures facilitates the development of mental manipulation, which is a domain-general factor underlying visual-spatial abilities. (Bar-henschweiger & Henik, 2024). Media components that allow students to take multiple perspectives, manipulate objects at different scales, and concretely explore three dimensions create rich, embodied experiences. The visual dimensions manifested in the TV component "Scroll of Shapes" and the Concept Map "The Shape Spectrum" provide graphical and conceptual representations that facilitate the development of students' procedural and conceptual knowledge. (Jun et al., 2024).

Studies on parallel collaboration in geometry learning show high effectiveness when students interact with geometric representations, supporting the design of group learning in this medium (Walkington et al., 2026). Research on collaborative problem-solving confirms that successful student pairs engage in more sketching and gesturing, activities facilitated by media components such as the "Folding Geometry" book (Popov et al., 2025).

The finding that embodied interaction with three-dimensional geometric objects enhances conceptual understanding supports the design of physical manipulatives in media (Walkington et al., 2024). The alignment of the findings of this study with previous studies strengthens the external validity and generalizability of the results.

This research uses a stepwise approach that is in line with the learning media development methodology that

emphasizes tiered formative evaluation to ensure practicality before full-scale implementation (Lisnani et al., 2025). In addition, the ease of manipulation of the media's physical components allows students of all ability levels to explore spatial concepts independently. Hands-on experiences through physical manipulatives such as the "Folding Geometry" Book and "Mageo" Magnets have been shown to increase student engagement through multisensory interactions, which support conceptual understanding in mathematics learning (Gashaj et al., 2025).

The main novelty of this research is the integration of five heterogeneous learning components into one integrated physical medium, something that has not been done before. The combination of dynamic visualizations, concept maps, interactive books, magnetic manipulatives, and game-based learning creates a comprehensive learning ecosystem. The non-digital approach is a significant contribution as a practical solution for schools with limited technological infrastructure, bridging the digital divide in access to quality education. This medium proves that learning innovation does not always depend on sophisticated technology, but rather on thoughtful instructional design that is responsive to local contexts. The integration of constructivist and experiential learning principles in media design results in active, student-centered learning.

The research findings offer significant practical implications for mathematics education. First, integrated non-digital media can be a viable alternative for schools with limited technological

resources, ensuring equitable access to quality learning. Second, teachers need to be trained to systematically integrate physical manipulatives into their learning, not just as sporadic aids. Third, developing similar media for other mathematics topics such as algebra, trigonometry, and statistics can enrich the repertoire of non-digital learning media. Fourth, a multi-component approach that integrates various learning modalities can be adapted to accommodate diverse student learning styles, creating a more inclusive and responsive learning environment.

The limitations of this study are that the trial was conducted only in one school and the scope of the material was limited to seven basic geometric shapes, while applications to more complex geometric concepts have not been explored.

IV. CONCLUSION

This research produces an integrated non-digital learning media "Space Capsule" to train the spatial visualization ability of junior high school students' solid geometry. It has succeeded in producing valid, practical, and effective learning innovations to improve the spatial visualization ability and mastery of junior high school students' spatial geometry material.

This improvement can be explained through embodied cognition, which highlights the importance of physical interaction in learning. When students directly touch and manipulate the components of the Space Capsule, they are better able to understand solid geometry concepts through concrete experience. In addition, haptic perception supports

stronger spatial understanding, as hands-on activities help students form clearer mental representations than visual learning alone.

The integration of five learning components, including dynamic visualizations, concept maps, interactive books, magnetic manipulatives, and educational games, creates a comprehensive learning ecosystem that accommodates the diversity of student learning styles. This medium proves that learning innovation does not always depend on sophisticated technology, but can be developed through thoughtful instructional design that is responsive to local contexts, making it a viable alternative for schools with limited technological infrastructure to continue providing quality geometry learning that optimally develops students' spatial skills. Future studies may explore the integration of Space Capsule with digital visualization tools to create a blended learning environment.

ACKNOWLEDGEMENT

The researcher would like to thank the Principal, teachers, and 7th grade students at SMPN 1 Maospati who were the subjects of this study. Furthermore, the researcher would like to thank the three experts who validated the media and questions in this study: Dr. Shahibul Ahyar, M.Pd., Dr. Chika Rahayu, M.Pd., and Mrs. Suripah.

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