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Effectiveness of PMRI Assisted by VERULI on Elementary School Students' Mathematical Problem-Solving Skills

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ABSTRACT

Mathematical problem-solving is an essential competency, yet many elementary students struggle due to limited conceptual understanding and difficulty relating mathematics to real-life contexts. Therefore, more meaningful learning approaches and media are needed to support their understanding. This study aimed to analyze the effectiveness of the Indonesian Realistic Mathematics Education (PMRI) approach assisted by VERULI media (Liter Volume Conversion Space), which is a manipulative medium in the form of various bottle sizes used to concretely visualize the process of volume unit conversion, on the mathematical problem-solving skills of fourth-grade elementary school students. The study used a quasi-experimental method with a nonequivalent control group design. Participants were selected through purposive sampling, involving 101 fourth-grade students from three schools. Data were collected using problem-solving tests, learning observation sheets, and student response questionnaires, and analyzed using the Kruskal–Wallis test and N-Gain calculation. The results showed that there was no significant difference in mathematical problem-solving skills among the groups based on the Kruskal-Wallis test (p=0,069). Nevertheless, the group that received PMRI learning assisted by VERULI media demonstrated the highest improvement in skills with an N-Gain value of 0,4281 (moderate category), compared to the PMRI group at 0,3199 and the conventional learning group assisted by VERULI media at 0,4052. The observation results indicated that all stages of learning were implemented very well. Furthermore, student responses to the learning were classified as positive, with a percentage of 84% in the PMRI group assisted by VERULI media, 75% in the PMRI group, and 78% in the conventional group assisted by VERULI media. These findings indicated that the PMRI approach assisted by VERULI media was effective in improving students' mathematical problem-solving skills on the topic of volume unit conversion.

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Introduction

In facing 21st-century learning, students were required to possess learning skills, literacy skills, and life skills, all of which needed to be mastered by elementary school students as a foundation for dealing with various problems they would encounter in daily life. In the context of 21st-century education, problem solving skills became one of the key competencies that students had to possess in order to face various learning and life challenges. According to the Peraturan Menteri Pendidikan Dasar dan Menengah Republik Indonesia Nomor 10 Tahun 2025, (2025), the graduate competency standard at the basic education level required students to be able to think analytically about various simple problems and ideas, as well as to be able to explore and select appropriate solutions to solve problems that arose in their surrounding environment.

According to Guarino et al. (2025, p. 15) "Learning through problem solving is important at every grade level because it supports students in building mathematical understanding and developing mathematical practices" meaning that problem-solving-based learning was very important to be implemented at every school level, because through the use of this type of learning, students could be helped to build a deep understanding of mathematical concepts while also developing the habit of engaging in problem-solving activities and fostering mathematical thinking skills. Based on the statement above, it could be said that problem solving skills were important to be trained in elementary school students, who were essentially at the first level of formal education for children. Through the use of problem-solving-based learning in mathematics instruction, students were not merely left to memorize formulas or other instant procedures, but were also invited to actively participate in learning activities; they were guided to understand mathematical logic in an enjoyable way and were trained to have critical thinking skills in facing real challenges or problems.

According to Polya (in Isrok'atun, 2023) problem solving skills consisted of four indicators: 1) understanding the problem, namely knowing what was asked and what was known in the question; 2) devising a plan, namely creating or writing down a plan; 3) carrying out the plan, namely writing or explaining the solution plan that had been devised; and 4) looking back. These four indicators served as the basis for assessing problem solving skills in this study. However, in reality, citing the results of the Programme for International Student Assessment (PISA) (2023), the findings showed that Indonesian students' mathematical literacy skills still required serious attention because their achievement had not yet been able to match the average set by OECD countries. It could also be said that almost no students in Indonesia were able to reach the category of top performers, which confirmed that most students in Indonesia were still unable to model complex mathematical situations and were still unable to select, compare, and evaluate appropriate problem-solving strategies to solve problem-based questions.

Preliminary observations conducted at one elementary school revealed that within a single class, a relatively large number of students still had difficulty solving word problems, particularly on the topic of volume unit conversion. One example was that students had difficulty understanding the problem presented in the question, which was essentially the first step in Polya's indicators. Moreover, when faced with the other problem-solving skill indicators, students were sometimes confused in working on the word problems. This was in line with research conducted by Sriwahyuni & Maryati (2022), which stated that in solving problem-solving-based questions, many students were still careless in performing calculations, had difficulty understanding the questions, and were often careless and hasty in completing the questions. Therefore, problem solving skills needed to be trained and taught to students at the elementary school level so that these skills could develop properly at the next level of education.

One learning innovation that had been widely applied to support the development of problem-solving skills was the Realistic Indonesian Mathematics Education (PMRI) approach, which made use of real-life contexts as the basis for building students' mathematical understanding. One characteristic of mathematics learning was the abstract nature of its content, meaning that the objects studied did not exist in concrete form but rather consisted of facts, concepts, calculation procedures, and principles that were interconnected within a structured system (Isrok'atun & Rosemala, 2018). This abstract nature inherent in mathematical content necessitated a learning approach capable of connecting mathematical concepts with realities close to students' lives.

According to Zulkardi (2002), there were five characteristics of the PMRI approach: 1) The use of contexts in phenomenological exploration, meaning that the mathematics learning process needed to begin with the introduction of a real and meaningful contextual problem for students. In relation to Polya's indicators, the use of real contexts supported students' ability to understand the problem (the first indicator), because students were able to connect the information in the question with their daily experiences; 2) The use of models or bridging by vertical instruments, meaning that students constructed their own models to bridge the gap between informal knowledge and formal mathematical knowledge. The models built by students supported the indicator of devising a plan (the second indicator), because the models; functioned as mathematical representations that helped students formulate solution strategies. 3) The use of pupils' own creations and contributions, meaning that students were given the opportunity to find solution strategies according to their own abilities. This was directly related to the indicator of carrying out the plan (the third indicator), because students actively designed and carried out their own solution procedures; 4) The interactive character of the teaching process, or interactivity, meaning that students were given the opportunity to interact with other students as well as with the teacher. This interaction supported the indicator of looking back (the fourth indicator), because through discussion, students were able to validate and re-explain their answers; 5) The intertwining of various mathematics strands or units, meaning the continuity of learning in which teachers could integrate other mathematical content into instruction.

In this regard, the Realistic Indonesian Mathematics Education (PMRI) approach could serve as a relevant alternative because it emphasized the use of real contexts as the foundation of learning. Through a series of activities designed by teachers based on everyday life situations, students were able to build a more concrete and meaningful understanding of concepts. This was consistent with the findings of a study conducted by Diana et al. (2023), who stated that the use of the PMRI approach in learning activities was proven to have an effect on problem solving skills compared to the use of a conventional approach. In addition, research conducted by Antely & Heryanto (2025), explained that learning with the PMRI approach placed students in problem situations relevant to real life. Through active involvement in exploring and solving these problems, students became more motivated to learn, so that their mathematical problem-solving skills developed more optimally. Ihsan et al. (2025), also stated that mathematics learning carried out using PMRI assisted by the concrete learning medium PAPABICA had a positive impact on students; the use of this learning medium provided opportunities for students to explore problem-solving strategies concretely, and students were also able to learn about other groups' approaches through intergroup discussion.

With the application of the PMRI approach in mathematics learning, students were able to develop their understanding independently by rediscovering ideas, concepts, and principles through the problem-solving process. When the PMRI approach was combined with concrete learning media that could support students' understanding of abstract and complex mathematical concepts, students' understanding of the material could become more optimal compared to using the PMRI approach alone. This condition was consistent with the results of a study conducted by Sya'diah et al. (2025), which stated that combining learning media with the PMRI approach was proven effective in improving students' understanding of mathematical concepts as well as increasing their learning motivation.

In this study, the medium used was VERULI (Volume Space Conversion/Konversi Ruang Liter). VERULI was a three-dimensional medium in the form of a replica volume container, designed in tiers according to the relationships between volume units, namely liters and milliliters. It worked by having students physically fill, transfer, or compare contents using the VERULI medium to visualize the unit conversion process, for example understanding that 1 liter was equivalent to 1.000 milliliters through direct observation of the comparison between container sizes. The VERULI medium consisted of several different containers, comprising one large 1-liter container, two medium 500 milliliter containers, and ten 100 milliliter containers. This medium differed from conventional unit-conversion staircases, which were generally two-dimensional and only presented the sequence of units symbolically without a manipulative experience. With VERULI, students not only read the sequence of units but also experienced the conversion process themselves through concrete activities, so that their conceptual understanding became deeper and longer-lasting.

Specifically, each component of VERULI was linked to Polya's problem solving indicators as follows: 1) for the indicator of understanding the problem, the visual display of VERULI helped students identify the known and asked-for volume units in the word problem; 2) for the indicator of devising a plan, the hierarchical structure of VERULI helped students determine the direction of conversion (upward or downward) so that they could design solution steps; 3) for the indicator of carrying out the plan, direct manipulation of the VERULI components helped students perform conversion calculations concretely and systematically; and 4) for the indicator of looking back, students were able to verify their answers by matching their calculation results against the physical comparison of the VERULI components.

Based on a review of previous studies, several patterns needed to be noted. First, various studies had examined the effect of the PMRI approach on problem solving skills in general (Diana et al., 2023; Antely & Heryanto, 2025), but most of these studies did not use volume unit conversion as the learning context. Second, there was research that combined PMRI with learning media (Ihsan et al., 2025), but the use of manipulative learning media such as VERULI based on volume unit conversion content had rarely been discussed. Third, the results of research on the combination of PMRI and learning media had not been entirely consistent; some studies reported significant improvements in conceptual understanding (Sya'diah et al., 2025), but their impact on word-problem solving skills specifically remained under-documented. Therefore, this study intended to fill this gap by empirically examining the effectiveness of the PMRI approach assisted by the VERULI medium on mathematical problem-solving skills in fourth-grade elementary school students.

Theoretically, elementary school-age children were at the concrete operational stage of cognitive development (approximately 7-11 years old), in which they found it easier to understand concepts through direct experience with real objects rather than through symbolic representation alone (Isrok'atun & Rosemala, 2018). This view was also reinforced by Bruner's (1966) concrete-pictorial-abstract learning approach, which emphasized that understanding of abstract concepts should ideally begin with concrete manipulative experience. Therefore, the use of the three-dimensional and directly manipulative VERULI medium was in accordance with the cognitive developmental characteristics of fourth-grade elementary school students

Kognitif: Jurnal Riset HOTS Pendidikan Matematika
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and supported the process of internalizing the concept of volume unit conversion more meaningfully.

Thus, the use of concrete objects became important in helping students understand the learning material and connect the concepts studied with conditions they encountered in daily life. This meant that with the combination of the PMRI approach and the VERULI medium, students were expected to have more meaningful learning, because students were not only trained to solve problems based on real contexts, but also received visual assistance in understanding the concept of volume unit conversion. Therefore, the use of the PMRI approach assisted by the VERULI medium was expected to be one of the efforts that could be made to improve students' ability to solve word problems on the topic of volume unit conversion.

Based on the description above, this study focused on the effectiveness of the PMRI approach assisted by the VERULI medium on the problem-solving skills of fourth-grade elementary school students in solving word problems. This study aimed to analyze the difference in effectiveness among the PMRI approach assisted by the VERULI medium, the PMRI approach alone, and the conventional approach assisted by the VERULI medium on students' mathematical problem-solving skills, so as to obtain information regarding the effectiveness of implementing the PMRI approach and the VERULI medium in improving elementary school students' mathematical problem-solving skills. Effectiveness in this study was determined based on the presence of a statistically significant difference in problem solving skill test results among the experimental groups.

Method

Type of Research

To obtain data that were objective and measurable, this study used a quantitative approach with an experimental method. The design used was a quasi-experimental design involving three different elementary schools as experimental classes, in the form of a pretest-posttest nonequivalent comparison group design, which was chosen because the study aimed to examine the effectiveness of applying the PMRI approach assisted by the VERULI medium on the mathematical problem-solving skills of fourth-grade elementary school students. Through the use of quantitative research, the information obtained could be more structured, since the data produced by the study could be used as more measurable information.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental Class 1 (E1)	O1	X1	O2
Experimental Class 2 (E2)	O3	X2	O4
Experimental Class 3 (E3)	O5	X3	O6

Note:
O1, O3, O5: Mathematical problem-solving skills before treatment (pretest).
O2, O4, O6: Mathematical problem-solving skills after treatment (posttest).
X1: Application of the PMRI approach assisted by the VERULI medium.
X2: Application of the PMRI approach.
X3: Application of the conventional approach assisted by the VERULI medium.

Population and Sample

The population in this study included all subjects targeted by the research, namely all fourth-grade elementary school students in the North Sumedang Sub-district (Kecamatan Sumedang Utara) who had obtained A accreditation, used the Merdeka Curriculum, and had more than one class group. Of the 35 public elementary schools located in the North Sumedang Sub-district, three elementary schools were selected as the sites for this study, namely SDN Tegalkalong, SDN Sukamaju, and SDN Rancapurut. The research sample was divided into three groups: a group that received PMRI learning assisted by the VERULI medium, consisting of 31 students; a group that received PMRI learning, consisting of 31 students; and a group that received conventional learning assisted by the VERULI medium, consisting of 39 students. The students who served as research subjects ranged in age from 9 to 11 years and consisted of 54 male students and 47 female students. The participation criteria in this study included: 1) being registered as an active fourth-grade student at the school where the research was conducted; 2) taking part in the entire series of research activities, including the pretest, the learning process (treatment), and the posttest; and 3) obtaining permission from the school to take part in the research. All students who met the participation criteria were involved in the research and took part in every stage of the study until its completion.

Instruments

Data in this study were collected through a problem-solving skills test. The test was used to determine the extent to which students' problem-solving skills improved after the learning treatment under investigation was applied. The test instrument consisted of eight pretest questions and eight posttest questions. The questions were presented as word problems, each of which addressed four problem solving indicators, namely understanding the problem, devising a plan, carrying out the plan, and looking back. The supporting non-test instruments consisted of a student response questionnaire, used to identify the extent to which the learning that was implemented had an impact on increasing students' motivation, enthusiasm, and understanding during the treatment, and a learning-implementation observation sheet, used to determine whether all learning stages had been carried out in accordance with the lesson design that had been prepared. In this way, the researcher was able to determine that, if an improvement in students' problem-solving skills occurred, one of the contributing factors was that the learning stages had been implemented as designed. One example of the problem-solving skills questions used by the researcher can be seen in the table below.

Table 2. Description of the Pretest and Posttest Questions

Basic Competency Pretest	Pretest
Students were able to calculate the remaining volume of water after use, involving volume units.	A scout troop carried 3 large bottles of water. Each bottle contained 3 liters of water. During the trip, they drank a total of 4,500 ml of water from the bottles using the cups they had brought. How many ml of water did they have left now? **Understanding the Problem** a. What information was given in the question? b. What needed to be found in the question? **Devising a Plan** c. What arithmetic operation was appropriate for answering the question above? **Carrying Out the Plan** d. Fill in the following using the arithmetic operation you determined! e. State the conclusion of your work!

Kognitif: Jurnal Riset HOTS Pendidikan Matematika
https://doi.org/10.51574/kognitif.v6i3.5312 Volume 6, No 3, July - September 2026, pp. 1073 –1094

	Looking Back f. Check your answer again! Was there any part that confused you?
Basic Competency Posttest	**Posttest**
Students were able to determine the additional volume needed so that three containers had the same volume.	Siti had three containers. The first container was a bottle containing 2 liters of water. The second container was a teapot containing 1,200 ml of water. The third container was a pot containing 2,500 ml of water. Siti wanted the three containers to contain the same amount, namely 3 liters, as a water supply. How many ml of water did Siti need to add to the three containers so that their contents were equal? **Understanding the Problem** a. What information did the question above contain? b. What needed to be found in the question above? **Devising a Plan** c. How would you solve the question above? Explain! **Carrying Out the Plan** d. Write your answer according to what you answered in point c! e. State the conclusion of your work! **Looking Back** f. Check your answer again! Count how many calculations you had performed!

Before the instrument was used, it was first validated by experts to determine whether it had been developed appropriately and was suitable for use. Content validation was carried out by three experienced classroom teachers, namely teachers from SDN Tegalkalong, SDN Sukamaju, and SDN Sukasirna I. The validators provided several suggestions for revising the instrument, including adding a column for writing answers to each question and improving the grammar to make it more suitable for elementary school students. The questions were then piloted at two different elementary schools; the results of the instrument validity test that was carried out are presented below.

Table 3. Validity Test Results of the Pretest and Posttest Questions

No	Sig.	Status	Correlation Coefficient	Description
1	0,000	Valid	0,774	High
2	0,000	Valid	0,857	Very High
3	0,000	Valid	0,883	Very High
4	0,000	Valid	0,905	Very High
5	0,000	Valid	0,923	Very High
6	0,000	Valid	0,889	Very High
7	0,000	Valid	0,882	Very High
8	0,000	Valid	0,779	High
9	0,003	Valid	0,466	Moderate
10	0,000	Valid	0,697	High
11	0,000	Valid	0,907	Very High
12	0,000	Valid	0,913	Very High
13	0,000	Valid	0,868	Very High
14	0,000	Valid	0,853	Very High
15	0,000	Valid	0,768	High
16	0,000	Valid	0,766	High

In addition to the validity test results, the results of the reliability test carried out for the pretest and posttest questions are presented below.

Table 4. Reliability Test of the Pretest and Posttest Questions

Cronbach's Alpha	N of Items
.949	8

Cronbach's Alpha	N of Items
Cronbach's Alpha	N of Items
.912	8

Based on the reliability test results above, the Cronbach's Alpha value for the pretest score was 0.994, and for the posttest score was 0.912, meaning both results fell into the very high category.

Procedure/Data Collection

This study was conducted at three elementary schools selected from a population of 35 elementary schools in the North Sumedang Sub-district area. The schools were selected using a purposive sampling technique based on several considerations, namely that the school had obtained A accreditation, used the Merdeka Curriculum, had more than one class group, had fourth-grade students with relatively similar characteristics, and was willing to serve as a research site. Based on these criteria, three schools were selected as research sites, namely SDN Sukamaju, SDN Tegalkalong, and SDN Rancapurut. The research subjects consisted of three classes that received different treatments, namely a class using the PMRI approach assisted by the VERULI medium, a class using the PMRI approach, and a class using the conventional approach assisted by the VERULI medium. The treatment assigned to each school was determined in accordance with the research design that had been established.

To obtain the required data, this study used data collection techniques in the form of tests and non-tests. The test technique was used to measure students' problem-solving skills, while the non-test technique was applied through a student response questionnaire and a learning-implementation observation sheet. The research procedure was carried out through the following stages: 1) administering the pretest to determine students' initial problem solving skills; 2) implementing the treatment in the three experimental classes, namely the class using the PMRI approach assisted by the VERULI medium, the class using the PMRI approach, and the class using the conventional approach assisted by the VERULI medium; 3) each learning activity was observed by the homeroom teacher of each class to determine the implementation of the learning; 4) administering the posttest to determine students' final problem solving skills; and 5) administering the student response questionnaire on the learning that had been carried out in the three experimental classes.

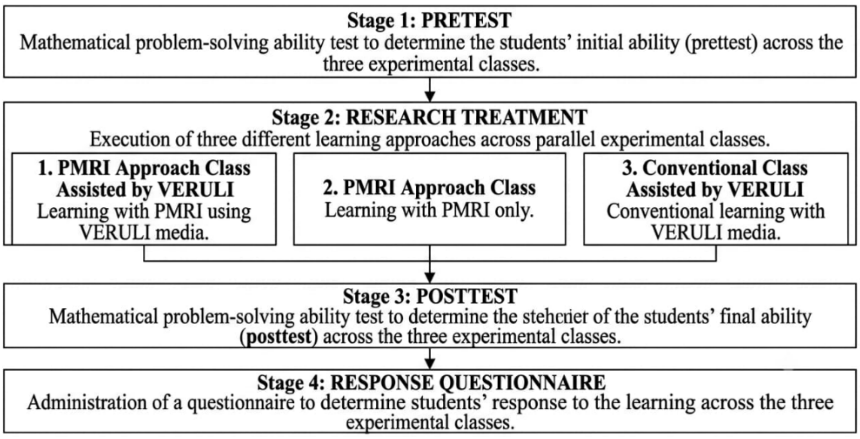

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Figure 1. Research Procedure Flow

Data Analysis

In this study, data analysis was carried out after the pretest and posttest data had been collected. The data were then processed using descriptive statistics to determine the mean score and the highest and lowest scores from the pretest and posttest results obtained. Prerequisite tests were then carried out, namely a normality test using the Shapiro-Wilk test and a homogeneity test using the Levene test. The hypothesis test used in this study was the Kruskal-Wallis test, because the data obtained were not homogeneous and there were three classes that needed to be tested. To determine the extent of the improvement resulting from the treatment given, the N-Gain test was used. The observation sheet data were analyzed using the following formula:

$$\frac{Score\ Obtained}{Maximum\ Score} \times 100\%$$

The questionnaire data were analyzed using the following formula:

$$P = \frac{f}{N} \times 100\%$$

Note:
P = percentage of student responses
f = total score obtained from data collection
N = number of respondents
Sudjono (in Asih & Muslim, 2023).

Research Findings

Implementation of the VERULI Media

The VERULI media was a concrete learning media designed as an instructional tool for the volume unit conversion topic. This learning media was used to help students understand the concept of volume units and the relationships among liter units through manipulative activities. The VERULI media consisted of several containers with different capacities, namely 1 liter, 500ml, and 100ml containers. The implementation of the VERULI media in this study was conducted over several meetings integrated with the PMRI approach. Through the VERULI media, students not only learned the concept of volume theoretically but also gained direct experience in measuring, comparing, estimating, and converting units of volume. These activities enabled students to build conceptual understanding gradually, thereby improving their problem-solving skills.

Figure 2. Media VERULI

In the first meeting, the teacher introduced the concept of volume through daily-life contexts, such as drinking water usage, water bottles, and water storage containers. After that, the teacher demonstrated the VERULI media, which consisted of one 1liter container, two 500ml containers, and ten 100ml containers. Students were asked to observe the shape, size, and capacity of each container. Subsequently, the teacher provided simple word problems related to the context of the VERULI media, followed by a question-and-answer session between the teacher and students while working on the given problems. In addition, students were given the opportunity to answer the word problems by conducting direct experiments using the VERULI media. In this first meeting, students began to understand the relationships among volume units through concrete experiences.

In the second meeting, students worked in groups using the VERULI media to solve problem-solving tasks presented in the form of word problems. In this activity, students discussed and collaborated to understand and solve the given problems. Each group member received a different problem, so the VERULI media was used sequentially by each student according to their problem-solving needs. Furthermore, students exchanged opinions and provided assistance to their group members in determining the appropriate solution strategies. Through these activities, students began connecting the experimental results obtained using the VERULI media with formal mathematical concepts, such as arithmetic operations of addition, subtraction, multiplication, division, and volume unit conversion. Thus, students' understanding of the volume concept was acquired not only through concrete experiences but also through the mathematization process toward a more abstract concept.

In the third meeting, students worked on word problems based on problem-solving skills with a higher level of complexity. Students continued to work in small groups; however, each student received a different problem, requiring them to understand and solve the problems independently. In this meeting, the use of the VERULI media was gradually reduced as a transition from concrete learning toward a more abstract understanding. Nevertheless, the given problems remained linked to the learning experiences students had gained through using the VERULI media in the previous meetings. During the learning process, students were asked to comprehend the information in the problem, determine the appropriate arithmetic operations, perform calculations to obtain solutions, and re-check their answers before submitting them as a group. Through these activities, the teacher was able to observe the extent to which students were capable of independently applying the concepts of volume and unit conversion learned through the VERULI media in solving problems. Therefore, this meeting served as an evaluation phase to examine the development of students' conceptual understanding and problem-solving skills after participating in the series of learning activities using the VERULI

Kognitif: Jurnal Riset HOTS Pendidikan Matematika
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media. The results of this study were processed to answer the formulated research question, namely the extent of the effectiveness of the PMRI approach aided by the VERULI media on students' word problem-solving skills. The following is the processed pretest and posttest data obtained from the three experimental classes.

Table 5. Recapitulation of Pretest Score Data Across Three Experimental Classes

Experimental Class	*N*	Score Range	Lowest Score	Highest Score	Average Score
PMRI approach aided by VERULI media experiment	31	0-100	18	92	53,13
PMRI approach experiment	31	0-100	37	72	55,68
Conventional approach aided by VERULI media experiment	39	0-100	11	78	38,79

Normality Test, Homogeneity Test, and Kruskal-Wallis Test for Pretest Scores Across Three Experimental Classes

Table 6. Statistical Tests for Pretest Scores Across Three Experimental Classes

Class	Normality Test (Shapiro-Wilk)		Homogenity Test	Mean Difference Test (Kruskal-Wallis)	
	Sig.	Description		Sig.	Sig.
PMRI approach aided by VERULI media experiment	.271	Normal	.000 (Non-homogeneous)	.000	There was no significant difference among the three Experimental classes
PMRI approach experiment	.228	Normal			
Conventional approach aided by VERULI media experiment	.738	Normal			

Normality Test of Pretest Scores Across Three Experimental Classes

The normality test for the pretest scores of the three experimental classes used the Shapiro-Wilk test with a predetermined significance level of 0.05. The decision-making rules for this test were as follows: (1) If the significance value was greater than 0.05 (Sig (2-tailed) $\geq$ 0.05), H_0 was accepted, meaning the data were normally distributed; and (2) If the significance value was less than 0.05 (Sig (2-tailed) < 0.05), H_1 was accepted, meaning the data were not normally distributed (Nurhaswinda et al., 2025, p. 58).

Based on the results of the normality test, it was found that the pretest data for the first experimental class implementing the PMRI approach aided by the VERULI media had a significance value of 0.271. Because this value exceeded the significance level of 0.05, the data for that class were declared normally distributed. In the second experimental class using the PMRI approach, a significance value of 0.228 was obtained. This value was also greater than 0.05, indicating that the data in the second experimental class met the normality assumption. Meanwhile, the third experimental class implementing conventional learning aided by the VERULI media obtained a significance value of 0.783. This value was above 0.05, showing that the data in the third experimental class were also normally distributed. Overall, all pretest data from the three experimental classes met the criteria for normal distribution. Consequently, the null hypothesis H_0 was accepted, and the alternative hypothesis H_1 was rejected.

Homogeneity Test of Pretest Scores Across Three Experimental Classes

The next step following the normality test was conducting a homogeneity test. This test was performed to determine whether the variance of the data in each research group was homogeneous or had an equal level of diversity. A homogeneity test can be conducted if the sample data are normally distributed; since the pretest data from all three classes were normally distributed, a homogeneity test was carried out using the following decision rules: **(1)** If the significance value was greater than 0.05 (Sig (2-tailed) ≥ 0.05), H_0 was accepted, meaning the data had equal variance or were homogeneous; and (2) If the significance value was less than 0.05 (Sig (2-tailed) < 0.05), H_1 was accepted, meaning the data did not have equal variance or were non-homogeneous (Nurhaswinda et al., 2025, p. 63).

Based on the homogeneity test results shown in the table above, a significance value (Sig.) of 0.000 was obtained. This value was smaller than the significance level of 0.05 (0.000 < 0.05). thus, it was concluded that the pretest data from the three experimental classes did not have equal variance and did not satisfy the homogeneity assumption. Therefore, the null hypothesis H_0 was rejected and the alternative hypothesis H_1 was accepted, indicating differences in variance among the tested groups.

Kruskal-Wallis Test of Pretest Scores Across Three Experimental Classes

After conducting the normality test which showed that all three experimental classes had normally distributed datathe homogeneity test revealed that the data from the three classes were non-homogeneous. Consequently, the Kruskal-Wallis test, a non-parametric test, was employed due to the non-homogeneity of the data. In accordance with Maulana (2016), the Kruskal-Wallis test can be used when either the normality assumption or the homogeneity assumption is violated. The hypotheses used were as follows: H_0: If the Sig. value ≥ 0.05, there was no significant difference in the rank distribution across the tested groups; and H_1: If the Sig. value < 0.05, there was a significant difference in the rank distribution across the tested groups (Inayah et al., 2025).

Referring to the calculation results, an Asymp. Sig. value of 0.000 was obtained. This value did not meet the criteria for accepting H_0 because it was smaller than the established significance threshold of 0.05. Hence, H_0 was rejected and H_1 was accepted. These results indicated that the students' initial word problem-solving skills were not at the same level across the three experimental classes. Furthermore, the recapitulation of the posttest scores from the three experimental classes is presented in the table below:

Table 7. Recapitulation of Posttest Scores Across Three Experimental Classes

Experimental Class	*N*	Score Range	Lowest Score	Highest Score	Average Score
PMRI approach aided by VERULI media experiment	31	0-100	49	98	76,48
PMRI approach experiment	31	0-100	37	91	69,65
Conventional approach aided by VERULI media experiment	39	0-100	34	89	62,95

Normality Test, Homogeneity Test, and Kruskal-Wallis Test for Posttest Scores Across Three Experimental Classes

Table 8. Statistical Tests for Posttest Scores Across Three Experimental Classes

Class	Normality Test (Shapiro-Wilk)		Homogeneity Test	Mean Different Test (Kruskal-Wallis)	
	Sig.	Description		Sig.	Description

Kognitif: Jurnal Riset HOTS Pendidikan Matematika
https://doi.org/10.51574/kognitif.v6i3.5312 Volume 6, No 3, July - September 2026, pp. 1073 –1094

PMRI approach aided by VERULI media experiment	.671	Normal	.006 (Non-homogeneous)	.002	There was no significant difference among the three Experimental classes
PMRI approach experiment	.483	Normal			
Conventional approach aided by VERULI media experiment	.064	Normal			

Normality Test of Posttest Scores Across Three Experimental Classes

The normality test for the posttest scores of the three experimental classes used the Shapiro-Wilk test with a predetermined significance level of 0.05. The decision-making rules for this test were as follows: (1) If the significance value was greater than 0.05 (Sig (2-tailed) ≥ 0.05), H_0 was accepted, meaning the data were normally distributed; and (2) If the significance value was less than 0.05 (Sig (2-tailed) < 0.05), H_1 was accepted, meaning the data were not normally distributed (Nurhaswinda et al., 2025, p. 58)

Based on the normality test results, it was revealed that the posttest data in the first experimental class implementing the PMRI approach aided by the VERULI media had a significance value of 0.671. Because this value exceeded the 0.05 significance level, the data in that class were declared normally distributed. In the second experimental class using the PMRI approach, a significance value of 0.483 was obtained. This value was also greater than 0.05, so the data in the second experimental class satisfied the normality assumption. Meanwhile, the third experimental class applying conventional learning aided by the VERULI media obtained a significance value of 0.064. This value was above 0.05, indicating that the data in the third experimental class were also normally distributed. Overall, all posttest data from the three experimental classes met the criteria for normal distribution. Thus, the null hypothesis (H_0) was accepted and the alternative hypothesis (H_1) was rejected.

Homogeneity Test of Posttest Scores Across Three Experimental Classes

After the data were confirmed to satisfy the normality assumption, the analysis proceeded with a homogeneity test to evaluate the equality of variance among the research groups. A homogeneity test can be conducted if the sample data are normally distributed; since the posttest data from all three classes were normally distributed, a homogeneity test was conducted with the following decision rules: (1) If the significance value was greater than 0.05 (Sig (2-tailed) ≥ 0.05), H_0 was accepted, meaning the data had equal variance or were homogeneous; and (2) If the significance value was less than 0.05 (Sig (2-tailed) < 0.05), H_1 was accepted, meaning the data did not have equal variance or were non-homogeneous (Nurhaswinda et al., 2025, p. 63). The test results showed that the Sig. value of 0.006 fell below the established significance threshold. This condition resulted in the rejection of the null hypothesis, leading to the conclusion that the posttest data across the three research groups had unequal variances.

Kruskal-Wallis Test of Posttest Scores Across Three Experimental Classes

After conducting the normality test which indicated that all three experimental classes exhibited normally distributed data the homogeneity test demonstrated that the data from the three classes were non-homogeneous. Therefore, the Kruskal-Wallis test (a non-parametric test) was executed. The hypotheses used were as follows H_0: If the Sig. value ≥ 0.05, there was no significant difference in the rank distribution across the tested groups and H_1: If the Sig. value < 0.05, there was a significant difference in the rank distribution across the tested groups (Inayah et al., 2025).

The test results indicated an Asymp. Sig. value of 0.002. This value was below the 0.05 significance threshold; hence, H_0 was rejected and H_1 was accepted. This finding indicated a significant difference in students' word problem-solving skills at the end of the learning process across the three experimental classes.

N-Gain Analysis of Pretest and Posttest Scores Across Three Experimental Classes

Based on the results obtained, the data indicated significant differences among the three experimental classes. Subsequently, an N-Gain analysis was performed to identify the growth rate of students' word problem-solving skills after participating in the learning process in each class. This analysis was conducted to compare the effectiveness of the treatments provided and to identify the class that experienced the highest increase in skills. The results of the N-Gain analysis of word problem-solving skills across the three experimental classes are presented below:

Table 9. N-Gain Test of Pretest and Posttest Scores Across Three Experimental Classes

N-Gain Value	*N*	Average N-Gain	Kruskal-Wallis Mean Different Test
PMRI approach aided by VERULI media experiment	31	0,4281	0.069 (There was no significant difference)
PMRI approach experiment	31	0,3199	
Conventional approach aided by VERULI media experiment	39	0,4052	

Based on the N-Gain calculations, the experimental class implementing the PMRI approach aided by the VERULI media obtained the highest average N-Gain compared to the other two experimental classes, which was 42.81 (0.4281). Descriptively, this result showed that this class experienced a higher increase in word problem-solving skills. Nevertheless, the mean difference test yielded a Sig. value of 0.069. Because this value was greater than the 0.05 significance level, it was concluded that there was no statistically significant difference in the improvement of word problem-solving skills among the three experimental classes.

Student Response Questionnaire Analysis Across Three Experimental Classes

In addition to processing pretest and posttest data, this study also processed questionnaire data aimed at determining students' responses to the implemented learning activities. The questionnaire was administered to students who underwent learning through the PMRI approach aided by the VERULI media, the PMRI approach, and the conventional approach aided by the VERULI media. The processed questionnaire results were used as supporting data to provide an overview of students' feedback on the applied instructional processes. The obtained student response questionnaire data are presented below:

Table 10. Student Response Questionnaire Results Across Three Experimental Classes

Class	Number of Students	Percentage	Category
PMRI approach aided by VERULI media experiment	31	84%	Very High
PMRI approach experiment	31	75%	High
Conventional approach aided by VERULI media experiment	39	78%	High

Kognitif: Jurnal Riset HOTS Pendidikan Matematika
https://doi.org/10.51574/kognitif.v6i3.5312 Volume 6, No 3, July - September 2026, pp. 1073 –1094

Based on the research findings, students across all three experimental classes responded positively to the implemented instruction. The results indicated that the applied learning approaches successfully enhanced students' learning motivation and enthusiasm, engaged their attention to participate actively during learning activities, and assisted in improving their comprehension of the material. Furthermore, the instruction fostered students' awareness of the importance of learning mathematics in daily life. It can be concluded from the research results that the instructional approaches implemented across the three experimental classes received favorable feedback from students and provided positive learning experiences.

Learning Implementation Observation Analysis

The learning implementation observation sheet was used as an instrument to observe and evaluate the execution of the learning process throughout the study. Observations were conducted by observers namely the homeroom teachers of each experimental class. The observers were tasked with monitoring the entire sequence of learning activities delivered by the researcher, from beginning to end. The observation was based on the learning stages defined in the research instrument, comprising preliminary activities, core activities, and closing activities. Thus, this observation sheet ensured that the learning process was carried out according to the prepared plans.

Table 11. Learning Implementation Data Across Three Experimental Classes

Class	Meeting	Observed	Not Observed	Persentage (%)
PMRI approach aided by VERULI media experiment	1	29	0	
	2	31	0	100%
	3	29	0	
PMRI approach experiment	1	28	0	
	2	28	1	98,8%
	3	29	0	
Conventional approach aided by VERULI media experiment	1	29	0	
	2	29	0	100%
	3	29	0	

Based on the data in the table above, the learning implementation in the first experimental class (PMRI approach aided by VERULI media) fell into the *Very Good* category. This was demonstrated by an implementation percentage of 100% from the first to the third meeting. These results showed that all learning stages preliminary, core, and closing activities were executed in accordance with the planned steps in the research instrument. In the second experimental class (PMRI approach), an implementation percentage of 98.8% was obtained, categorized as *Very Good*. The percentage did not reach 100% because one instructional step in the second meeting was not carried out during the lesson. Nevertheless, the overall instruction in this class proceeded according to plan and fulfilled the *Very Good* criteria. Meanwhile, in the third experimental class (conventional approach aided by VERULI media), learning implementation also achieved the *Very Good* category with a percentage of 100%. This result showed that every learning step across all meetings (Meetings 1 to 3) was executed according to the designed lesson plans. Consequently, the implementation of learning across all three experimental classes was executed exceptionally well and in compliance with the planned research procedures.

Discussion

Based on the presented research results, the effectiveness of using the PMRI approach aided by the VERULI media was proven to enhance students' word problem-solving skills in 4th grade elementary school, achieving an N-Gain value of 0.4281. This improvement occurred because the instruction delivered was no longer merely a transfer of knowledge from the teacher to the students; rather, it provided freedom for students to reinvent mathematical concepts according to their own level of logical understanding. This statement aligns with the ideas of Hans Freudenthal, who viewed mathematics as the product of human activity in understanding and solving various problems (Wijaya, as cited in Septiana et al., 2022).

Building upon the notion that mathematics is constructed through human activity, Gravemeijer designed three main principles serving as the conceptual framework of the PMRI approach, namely: 1) the principle of guided reinvention and progressive mathematizing, meaning that under this principle, students were guided to reinvent mathematical concepts through meaningful experiences; 2) the principle of didactical phenomenology, meaning that students were presented with contextual problems arranged by the teacher so that those problems could connect directly with the mathematical topic to be learned; 3) the principle of emergent modeling, meaning that students were trained to transform solutions from given contextual problems into a more formal mathematical form, resulting in problem solutions in the form of more general mathematical knowledge (Suryanto et al., 2010).

According to the data obtained from the field, the effectiveness of the PMRI approach aided by the VERULI media in achieving a higher N-Gain value compared to other classes was influenced by the realization of PMRI's core characteristics during the learning process. First, the characteristic of use of contextual problems was clearly evident in the initial phase of instruction. The word problems presented to students drew upon daily-life situations, such as measuring container capacities or liquid volume in liters and milliliters. This real-life context was proven to assist students in identifying known and required information in the problems before formulating solution strategies. This finding is consistent with research conducted by Diana et al. (2023), titled "Kemampuan Pemecahan Masalah Matematika Siswa Materi Ukuran Pemusatan Data Menggunakan Pendekatan PMRI," which demonstrated that the PMRI approach had a positive impact on students' mathematical problem-solving skills. Their study revealed that the majority of students in the experimental class were able to solve problems according to problem-solving indicators because they were accustomed to recognizing problems within familiar contexts. The use of contextual problems in PMRI was proven to help students activate prior knowledge, enabling the step of understanding the problem (the first step in Polya's problem-solving framework) to be executed more effectively.

Second, the characteristic of use of models was realized through the inclusion of the VERULI media as a bridge between concrete understanding and formal mathematical symbols. During instruction, students first practiced pouring water between containers using the VERULI media to build an intuitive understanding of volume relationships. This concrete experience was then gradually transformed into mathematical models, such as the conversion equation 1 liter = 1.000 milliliters. The VERULI media functioned as a bridging model that guided students from understanding real situations toward more abstract symbolic representations. The role of concrete media as a bridge supports Piaget's theory of cognitive development, which states that children aged 10–11 years are still in the concrete operational stage, requiring concrete objects to construct mathematical concepts meaningfully (Wardani, 2022). This aligns with findings by Ermawati et al. (2023) regarding the use of concrete instructional media (MACAN), which positively impacted students' material comprehension

Kognitif: Jurnal Riset HOTS Pendidikan Matematika
https://doi.org/10.51574/kognitif.v6i3.5312 Volume 6, No 3, July - September 2026, pp. 1073 –1094

process. This success was demonstrated by a significant increase in student learning achievements after instruction, as evidenced by higher posttest scores compared to pretest scores. Furthermore, their study revealed that every indicator of mathematical problem-solving skills showed improvement. Using concrete media helped students grasp learning concepts better, thereby enhancing their proficiency in solving tasks requiring problem-solving skills. Moreover, Ayumni et al. (2025) stated that media-assisted RME was proven superior in improving students' mathematical problem-solving skills compared to direct instruction, as media facilitated the process of active knowledge construction.

Third, the characteristic of use of students' contribution was observed in the emergence of diverse solution strategies developed independently by students. Rather than imitating procedures provided by the teacher, students constructed their own solution methods based on the understanding formed through interaction with the VERULI media. The emergence of these varied strategies provided evidence that the reinvention process by students genuinely occurred. In line with research by Khotimah et al. (2024), the application of the PMRI approach was shown to foster active student engagement in the mathematical problem-solving process. Through group learning activities, students expressed high levels of satisfaction as they had opportunities to discuss and exchange ideas with their peers. The implemented instruction successfully created a learning environment that encouraged active participation, as reflected in students' heightened enthusiasm and motivation to solve the assigned problems. Additionally, each group's ability to complete tasks effectively indicated that the learning process functioned optimally, thereby supporting the development of students' mathematical problem-solving skills. Findings by Laia et al. (2025), further reinforced this result by demonstrating that a realistic approach encouraged students to actively construct their own understanding, ultimately enhancing their overall mathematical skills.

Fourth, the characteristic of interactivity was manifested in group discussion activities that characterized a major portion of the learning sessions. As students discussed their problem solutions with group members, they indirectly cross-checked the accuracy of each other's answers. This process corresponded directly to the looking back phase in Polya's problem-solving model. Ariyanto et al. (2024), stated that small-group interaction in media-assisted learning was proven effective in improving problem-solving skills because students mutually corrected and complemented one another's understanding.

Fifth, the characteristic of intertwining was reflected in how students understood the relationship between liter and milliliter units not as isolated facts, but as interconnected parts of a conversion system. When students understood that 1 liter = 1.000 milliliters, they naturally developed an understanding of the multiplication and division operations used in unit conversions and their connection to the broader concept of volume. This inter-concept connectedness strengthened students' ability to carry out the plan, as they did not merely memorize formulas but understood the underlying relationships.

Based on the analysis of these five PMRI characteristics namely use of contextual problems, use of models of bridging by vertical instrument, use of student's contribution, interactivity, and intertwining of learning strands (Gravemeijer; Zulkardi; Zulkardi & Puri, as cited in Fauziah et al., 2020) it can be stated that VERULI assisted PMRI was effective because the instruction combined two simultaneous strengths: the use of contextual problems connecting mathematics with real life, and concrete media bridging intuitive understanding toward formal knowledge. These two elements worked synergistically to support every stage of problem solving, from understanding the problem, devising a plan, carrying out the plan, to looking back at the solution. This confirms that the effectiveness of PMRI stemmed not only from its pedagogical approach but also from the selection of learning media capable of concretizing abstract mathematical concepts. This is consistent with research by Ni'mah (2022), which stated that students exhibited active and enthusiastic participation during the learning process. Moreover, the use of video media featuring real-world objects, such as clocks, helped learners connect instructional content with everyday experiences. This connection between material and real contexts contributed to the improvement of learners' problem-solving skills through a better understanding of learned concepts. Wanabuliandari et al. (2024) reinforced this finding by showing that realistic mathematics education aided by modules or digital media based on local contexts significantly increased students' mathematical skills compared to conventional instruction.

Based on the discussion and previous research results above, it can be concluded that through instruction using the PMRI approach, students' mathematical problem-solving skills can experience significant enhancement and positive impact. Furthermore, in this study, the PMRI approach was combined with concrete learning media that assisted students by providing a clear visualization of volume unit conversion material. According to Jean Piaget, knowledge is not acquired directly from the social environment; instead, the social environment serves as a stimulus that triggers cognitive conflict within the individual, thereby prompting the process of knowledge construction (Habsy et al., 2023). In his theory of cognitive development, Piaget explained that children's thinking progresses through four stages, one of which is the concrete operational stage experienced between the ages of 7 and 11 years. Thus, 4th-grade elementary school students, who average 10–11 years of age, fall within this phase. At this stage, children begin to demonstrate the ability to understand conservation concepts, categorize objects, view items from different perspectives, and think more logically (Bustomi et al., 2024). In other words, the VERULI media precisely matched the cognitive needs of students at this stage by providing concrete objects that could be directly manipulated, allowing abstract concepts of volume unit conversion to be meaningfully understood rather than simply memorized.

The use of learning media in this study aimed to provide visual assistance and learning experiences that facilitated students' understanding of the taught material. Through the learning media, students were directly involved in learning activities and carried out volume unit conversion tasks alternately with classmates. They also found it easier to solve word problems due to the support provided by the VERULI media. As stated by Ayunis & Belia (2021), a realistic approach grounded in real contexts and direct experience consistently contributes positively to elementary students' mathematical skills.

Based on the analysis conducted, it can be stated that learning through the PMRI approach aided by the VERULI media exerted a positive impact on students' word problem-solving skills. This effectiveness was realized because all five PMRI characteristics use of context, use of models, student contribution, interactivity, and concept intertwining were not merely present theoretically but were fully implemented in every phase of instruction and synergistically supported by the presence of the VERULI media as a concrete tool bridging concrete understanding to formal knowledge. The connection between media and real contexts also contributed to the overall enhancement of learners' word problem-solving skills. This success proves that integrating PMRI with contextual concrete media is an instructional strategy that not only enhances conceptual understanding but also comprehensively and sustainably develops students' mathematical word problem-solving skills.

Conclusion

Based on the research findings, it was concluded that the implementation of the PMRI approach aided by the VERULI media was effective in enhancing students' word problem-solving skills in the volume unit conversion material. This effectiveness was demonstrated by

Kognitif: Jurnal Riset HOTS Pendidikan Matematika
https://doi.org/10.51574/kognitif.v6i3.5312 Volume 6, No 3, July - September 2026, pp. 1073 –1094

the Kruskal-Wallis test results, which indicated no significant difference in problem-solving skills among the experimental groups (0.069 > 0.05). However, based on the obtained N-Gain values, the PMRI approach aided by VERULI media class achieved a score of 0.4281, the PMRI approach class achieved 0.3199, and the conventional approach aided by VERULI media class achieved 0.4052, all falling into the moderate category. Looking at the N-Gain acquisition, the class implementing the PMRI approach aided by VERULI media obtained a higher result compared to the other classes, meaning that this first experimental class exerted a more dominant influence than the others. The research findings also indicated that using the PMRI approach aided by the VERULI media helped students understand the concept of volume unit conversion through concrete and contextual learning experiences. Based on the observation results of learning implementation and student responses, learning through PMRI aided by the VERULI media encouraged students' active participation in learning activities, group discussions, and the process of independently discovering mathematical concepts. The use of the VERULI media consisting of containers with capacities of 1 liter, 500 milliliters, and 100 milliliters helped students visualize the relationships among volume units, making the initially abstract concepts easier to comprehend. Nevertheless, this study had limitations as it was conducted solely with 4th-grade students, restricted to volume unit conversion material, and carried out in a single school; thus, the generalization of the findings should be made with caution. Therefore, future research is recommended to apply the PMRI approach aided by the VERULI media across different educational levels, mathematical topics, and school characteristics to obtain a broader overview of its effectiveness. Additionally, further studies can examine the impact of the VERULI media on other mathematical abilities, such as critical thinking, mathematical communication, and mathematical reasoning skills.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Auhor Contributions

A.K.S. contributed to the execution of the research, data collection, data processing and analysis, as well as the drafting of the manuscript. M. participated in the conceptual development and theoretical framework of the study, methodology formulation, as well as providing guidance and feedback throughout the research process. I. contributed to the validation of research instruments, review of data analysis results, and discussion of research findings. All authors declare that they have read and approved the final version of this paper. The total percentage contribution for the conceptualization, execution, drafting, and proofreading of this paper is as follows: A.K.S.: 50%, M.: 25%, and I.: 25%.

Data Availability Statement

The authors declare that data sharing is not applicable, as no new data were created or analyzed in this study.

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