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Students' mathematical understanding ability in curved-sided space structure material reviewed from self-confidence through learning with potrame media

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ABSTRACT

This study examined the effect of POTRAME, an augmented-reality (AR)-enhanced pop-up book medium, on ninth-grade students' mathematical understanding of curved-sided three-dimensional shapes and explored differences by self-confidence. A mixed-methods design was employed, with quantitative data collected first, followed by qualitative explanation (Toyon, 2021). The quantitative phase used a quasi-experimental one-group pretest–posttest design involving 25 ninth-grade students from one public junior high school in Semarang City, selected through cluster random sampling (Li et al., 2024). The qualitative phase involved six students representing high, moderate, and low self-confidence categories. The mathematical understanding test and self-confidence questionnaire were validated by three experts and piloted. The test obtained an Aiken's V of 0.81 and Cronbach's alpha of 0.79, while the questionnaire obtained an Aiken's V of 0.83 and Cronbach's alpha of 0.85, indicating acceptable validity and reliability (Maulana, 2022; Zakariya, 2022). Quantitative data were analyzed using the paired-sample t-test and N-Gain index, while qualitative data were analyzed descriptively through data reduction, display, and conclusion drawing (Rofiah, 2022). Mean scores increased from 14.31 at pretest to 74.96 at posttest, with an N-Gain of 0.71 (high category) and a significant paired-sample t-test result ($p < .05$). Higher-self-confidence students demonstrated more coherent and systematic conceptual understanding, whereas lower-self-confidence students had greater difficulty organizing solutions. Because the study lacked a control group, the findings indicate an association between POTRAME use and improved mathematical understanding rather than definitive causal effects. The results provide exploratory support for further evaluation of AR-based pop-up book media in geometry instruction.

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Introduction

Mathematical understanding the capacity to grasp a concept, restate it in one's own words, and connect it to other, previously acquired concepts is widely regarded as a core competency in mathematics education because it allows students to solve problems meaningfully rather than by rote procedure. Recent cognitive accounts describe this understanding as emerging specifically through the process of connecting a new concept to closely related, superordinate, or convertible concepts already present in a learner's cognitive structure (Yang et al., 2021). In educational practice, however, students' mathematical understanding remains suboptimal, particularly in geometry, a topic that demands visualization skill and a deeper grasp of relationships among abstract elements (Repriani & Jupri, 2025).

Mathematics, and geometry in particular, continues to be perceived as difficult because it requires abstract thinking and spatial visualization (Medina Herrera et al., 2024; Muhammad et al., 2025). Students frequently struggle to relate the elements of three-dimensional shapes to one another and to connect visual representations with the corresponding mathematical models (Aprilia et al., 2024; Apriza et al., 2024). This difficulty is reflected in recent national numeracy data: an analysis of elementary and junior secondary students' performance on Minimum Competency Assessment (AKM)-based numeracy items found that 76% of students scored in the moderate-to-very-low category, with the geometry-and-measurement content domain among the weakest of the four numeracy domains tested (Supriyanto et al., 2024). A comparable pattern was observed at the research site: of 24 ninth-grade students evaluated on curved-sided three-dimensional shapes at one public junior high school in Semarang City, only 3 students (12.5%) met the minimum learning-objective criterion, while 21 students (87.5%) did not. This single-school figure is reported here descriptively, as the rationale for selecting this class as the object of a classroom-embedded pilot study, rather than as a claim that the school's performance is statistically representative of, or different from, the national pattern; the broader AKM evidence above is what establishes the wider urgency of the problem.

These low outcomes are thought to be related, in part, to limited use of learning media that can support optimal visualization of geometric concepts (Ayna & Sari, 2024). Curved-sided three-dimensional shapes in particular require media that let students visualize concrete forms so that abstract relationships among radius, height, surface area, and volume become easier to grasp (Aprilia et al., 2024). This concern is consistent with the global education agenda under Sustainable Development Goal 4, which calls for quality, inclusive, and meaningful education for all learners (United Nations, 2023; Pham Xuan & Håkansson Lindqvist, 2025); strengthening conceptual understanding is central to that agenda because it underpins the sustainable mastery of mathematical concepts (Komarudin et al., 2023).

Beyond cognitive factors, success in learning mathematics is also shaped by affective factors, particularly self-confidence students' belief in their own capacity to understand and solve mathematical problems. Scoping-review evidence indicates that such self-belief is future-oriented, task-specific, and distinct from related constructs such as self-concept, and that it is consistently associated with students' engagement and performance in mathematics (Street et al., 2024). Students with low self-confidence tend to hesitate, participate less in discussion, and avoid attempting problems, whereas students with high self-confidence are more willing to try multiple problem-solving strategies and persevere through difficulty (Wahyuni et al., 2024); self-confidence has repeatedly been linked to stronger mathematical communication and problem-solving performance (Yuniarti et al., 2023). An analysis of mathematical understanding is therefore more complete when it also accounts for students' self-confidence.

One promising route to strengthening both mathematical understanding and self-confidence is technology-based learning media that render abstract objects in a more concrete, interactive form. Augmented reality (AR) is one such technology: systematic reviews of AR use in mathematics education report consistent gains in geometric conceptual understanding, spatial visualization, and engagement across a range of classroom contexts (Beisenbayeva et al., 2024; Husna et al., 2025; Nadzeri et al., 2024), a pattern that is theoretically consistent with the view that combining visual and interactive representations reduces the cognitive burden of transforming abstract geometric information into a mental model (Kumalasari & Efendiy, 2025; Putri et al., 2025).

POTRAME is a learning medium that integrates a pop-up book with AR: scanning the physical pop-up pages with a companion application triggers a three-dimensional, manipulable visualization of curved-sided solids, so that the physical and digital representations are experienced together rather than separately. Through this medium, students can examine curved-sided three-dimensional shapes in a more concrete, interactive, and engaging way, which is expected to support deeper understanding of how the elements of these shapes relate to one another. A prior classroom implementation of POTRAME reported improved conceptual understanding of curved three-dimensional shapes among junior secondary students (Dewi et al., 2025).

However, that prior study like most AR-medium studies cited above evaluated the medium's effect on cognitive outcomes alone, without accounting for how students' affective characteristics might shape the way they use and benefit from the visualization it provides (Aprilia et al., 2024; Apriza et al., 2024; Dewi et al., 2025). The specific theoretical gap this study addresses is therefore not simply whether AR-based media can improve geometry scores a question the literature above has already answered affirmatively in several contexts but whether the *pattern* of conceptual understanding that emerges from AR-supported visualization differs systematically across levels of self-confidence, and if so, in what way. Clarifying this pattern matters because it indicates whether a visualization-only intervention is sufficient on its own or needs to be paired with affective scaffolding for lower-confidence learners. This study addresses that gap directly by describing students' mathematical understanding of curved-sided three-dimensional shapes after POTRAME-supported instruction in relation to their self-confidence category, using a quasi-experimental one-group pretest–posttest design followed by a purposive qualitative phase.

Based on the foregoing, this study aims to (1) examine the effect of POTRAME media on students' mathematical understanding of curved-sided three-dimensional shapes, and (2) describe students' mathematical understanding in relation to their self-confidence level following instruction with this medium. Given the single-group, single-site design, the findings are intended as exploratory evidence to inform larger, controlled follow-up studies rather than as a definitive causal claim about POTRAME's effectiveness.

Method

Research Design

This study used a mixed-methods approach with an explanatory sequential design, in which quantitative data are collected and analyzed first, and qualitative data are subsequently collected to explain and deepen the interpretation of the quantitative results (Toyon, 2021). Table 1 summarizes the two phases, their purpose, and their approximate timing.

Table 1 <Summarizes>

Phase	Purpose	Activities	Approximate Timing
1. Quantitative	Assess change in mathematical understanding after POTRAME instruction	Pretest → four POTRAME learning sessions → posttest; self-confidence questionnaire	Weeks 1–2
Integration point	Identify self-confidence categories to guide qualitative sampling	Categorize students into high/moderate/low self-confidence using mean ± SD	End of Week 2
2. Qualitative	Explain quantitative results in depth	Semi-structured interviews with 2 students per self-confidence category (n = 6); thematic analysis of interview transcripts and test work	Week 3

In the quantitative phase, the study used a quasi-experimental one-group pretest–posttest design, a design commonly used in classroom-based intervention studies where random assignment to a control group is not administratively feasible (Toyon, 2021), and comparable in structure to other single-group conceptual-understanding intervention studies in mathematics education (Tonra et al., 2022). Because this design lacks a control or comparison group, it cannot rule out alternative explanations for score change, such as maturation or repeated-testing effects; this limitation is addressed explicitly in the Discussion. The subsequent qualitative phase described students' mathematical understanding in relation to their self-confidence level, drawing on test results and semi-structured interviews.

Time and Research Setting

This study was conducted during the second semester of the 2024/2025 academic year at a public junior high school in Semarang. The research subjects were ninth-grade students in a mathematics class covering curved three-dimensional shapes.

Population and Sample

The population comprised all 2024/2025 ninth-grade classes at the school. One class (n = 25) was selected as the research sample using cluster random sampling, in which an intact, pre-existing class rather than individual students is the unit that is randomly selected; this technique is commonly used in school-based intervention

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research because instruction is naturally organized by intact classes (Li et al., 2024). With a single cluster of 25 students, the design has limited statistical power to detect small effects and does not allow the between-cluster variance that a multi-cluster design would allow to be estimated or controlled; per-condition samples of at least 30, ideally drawn from multiple clusters, are recommended for adequately powered future replications of this design (Li et al., 2024). This limitation, together with the single-site sampling frame, is treated as a boundary condition on generalizability rather than as a defect specific to this study, and is revisited in the Discussion.

For the qualitative phase, six students were selected purposively based on their self-confidence questionnaire scores: two each from the high, moderate, and low self-confidence categories, for in-depth analysis through interviews.

Research Procedure

The study proceeded in three stages. First, students completed a pretest to establish their initial mathematical understanding of curved-sided three-dimensional shapes. Second, mathematics instruction using the POTRAME medium was delivered across four sessions. The POTRAME medium integrates a pop-up book with an AR companion application: scanning a page displays a manipulable three-dimensional visualization of the corresponding curved-sided solid, allowing students to view the shape from multiple perspectives (Figures 1 and 2). Each session followed the same three-part structure an introductory activity in which the teacher outlined the day's objective, a core activity in which students scanned the POTRAME pages, explored the resulting three-dimensional visualization in small groups, and worked through concept- and formula-related problems with the teacher as facilitator, and a closing activity in which students reflected on and presented their reasoning to the class. Classroom observation during all four sessions indicated consistent student engagement with the medium. Third, after the fourth session, students completed a posttest using the same instrument as the pretest and a self-confidence questionnaire; questionnaire scores were used to group students into high, moderate, and low self-confidence categories, from which six students were subsequently selected for interviews.

Figure 1 <POTRAME Pop-Up Book>

Figure 2 <POTRAME Application Interface>

Data and Research Instruments

Three instruments were used: a mathematical understanding test, a self-confidence questionnaire, and a semi-structured interview guide. The mathematical understanding test measured students' understanding through pretest and posttest administrations, built around indicators of explaining, representing, connecting, and applying concepts in problem-solving, consistent with contemporary accounts of mathematical understanding as the ability to connect a concept to related representations (Yang et al., 2021). The self-confidence questionnaire used a four-point Likert scale built around established self-confidence indicators for mathematics learning (Street et al., 2024; Wahyuni et al., 2024).

Both instruments were reviewed by three content experts prior to use; content validity was quantified using Aiken's V, an index recommended for translating expert-panel judgments into an objective validity coefficient (Kania & Kyaruzi, 2023). The mathematical understanding test obtained an Aiken's V of 0.81, and the self-confidence questionnaire obtained an Aiken's V of 0.83; both exceed the 0.80 threshold conventionally treated as indicating high content validity. Internal-consistency reliability was estimated with Cronbach's alpha following a pilot administration; the mathematical understanding test achieved $\alpha = 0.79$ and the self-confidence questionnaire achieved $\alpha = 0.85$, both within the range conventionally considered acceptable-to-good for classroom-level instruments, though Cronbach's alpha is sensitive to sample heterogeneity and item count and should be interpreted as one piece of reliability evidence rather than a complete psychometric characterization (Zakariya, 2022). These coefficients are broadly consistent with values reported for a comparably structured self-confidence rubric in Indonesian junior secondary settings (Maulana, 2022).

The self-confidence questionnaire scores were used to group students into high, moderate, and low categories using the mean-and-standard-deviation procedure summarized in Table 2, a categorization approach widely applied in psychometric analyses of Indonesian classroom-affect instruments (Maulana, 2022).

Table 2 <Categories of Self-Confidence>

Score Range	Category
$x \geq (\bar{x} + SD)$	High
$(\bar{x} - SD) \leq x < (\bar{x} + SD)$	Moderate
$x < (\bar{x} - SD)$	Low

Sumber: Arikunto (2021).

Interview Protocol and Qualitative Coding

The interview guide contained open-ended questions probing how students used the POTRAME visualization, how they approached solving curved-surface problems, and what difficulties they encountered; the same guide was used across all six interviews, and each interview was audio-recorded and transcribed verbatim to support consistent coding. Two coders independently reviewed the transcripts and applied a shared codebook derived from the mathematical-understanding indicators described above; coding disagreements were resolved through discussion, and code definitions were refined iteratively across two review cycles to improve consistency between coders.

Data Collection Technique

Research data were collected using several methods, including tests, questionnaires, and interviews. Tests were administered as pretests and posttests to determine improvements in students' mathematical comprehension skills after learning using the POTRAME medium. Questionnaires were used to determine students' level of self-confidence in mathematics learning. Meanwhile, interviews were conducted with selected research subjects to obtain more in-depth information regarding students' mathematical comprehension skills.

Data Analysis Technique

Quantitative data analysis was performed to determine improvements in students' mathematical comprehension skills using pretest and posttest scores. The improvement in skills was analyzed using the N-Gain value, a measure of the extent of improvement in students' learning outcomes.

The N-Gain value is calculated using the following formula:

$$\mathrm{N - Gain} = \frac{\text{posttest} - \text{pretest}}{\text{maximum score} - \text{pretest}}$$

The N-Gain score is then interpreted based on specific criteria to determine the level of improvement in students' mathematical comprehension. The criteria for interpreting N- Gain scores are presented in Table 3.

Table 3 <N-Gain Categories>

N-Gain Value	Criteria
$0.70 \le g \le 1.00$	High
$0.30 \le g \le 0.70$	Medium
$0.00 \le g \le 0.30$	Low
$g = 0.00$	No increase
$-1.00 \le g < 0.00$	A decrease occurs

Sumber: Sukarelawan et al. (2024).

A paired-sample t-test was conducted at the 0.05 significance level to determine whether the difference between pretest and posttest scores was statistically significant. All quantitative analyses were performed using SPSS software.

Qualitative data were analyzed descriptively following the interactive model of data reduction, data display, and conclusion drawing/verification, an approach widely applied to classroom interview and documentary data in Indonesian education research (Rofiah, 2022). The data analyzed were drawn from written test work and interview transcripts, providing a more detailed picture of the relationship between self-confidence and students' mathematical understanding after POTRAME-supported instruction.

Results and Discussions

This study involved 25 ninth-grade students (13 male, 12 female) from one public junior high school in Semarang City. The results below report the analyzed quantitative and qualitative outcomes addressing the study's two objectives; the POTRAME medium and the instructional procedure used to generate these outcomes are described in the Method section above.

Tabel 4 <Descriptive Statistics of Pretest and Posttest>

	Pretest	Posttest
N (valid)	25	25
Mean	14.31	74.96
Std. Deviation	4.790	17.257
Minimum	6	39
Maximum	26	100

Students' mean pretest score was 14.31, rising to a mean posttest score of 74.96 after POTRAME-supported instruction. This increase is consistent with an improvement in students' mathematical understanding of curved-sided three-dimensional shapes over the course of the intervention.

Normality Test

A Shapiro-Wilk test was used to check normality prior to hypothesis testing, given the sample size ($n < 50$)

Table 5 <Results of the Shapiro-Wilk Normality Test.>

	Statistic	df	Sig.
Pretest	.931	25	.092
Posttest	.956	25	.346

Both significance values exceeded 0.05, so the null hypothesis of normal distribution was retained for both pretest and posttest data, supporting the use of the parametric paired-sample t-test in the next step.

Hypothesis Testing

Table 6 <Results of the Paired-Sample t-Test (Pretest–Posttest)>

Mean Difference	Std. Deviation	t	df	Sig. (2-tailed)
−60.840	17.046	−17.846	24	.000

The significance value ($p = .000$) was below .05, indicating a statistically significant difference between students' pretest and posttest scores under this one-group design.

Table 7 <N-Gain Analysis Results>

N	Minimum	Maximum	Mean	Std. Deviation
25	.29	1.00	.7107	.20195

The mean N-Gain was 0.71, in the high category, indicating a substantial improvement in mathematical understanding across the sample as a whole, within the bounds of the one-group design described above.

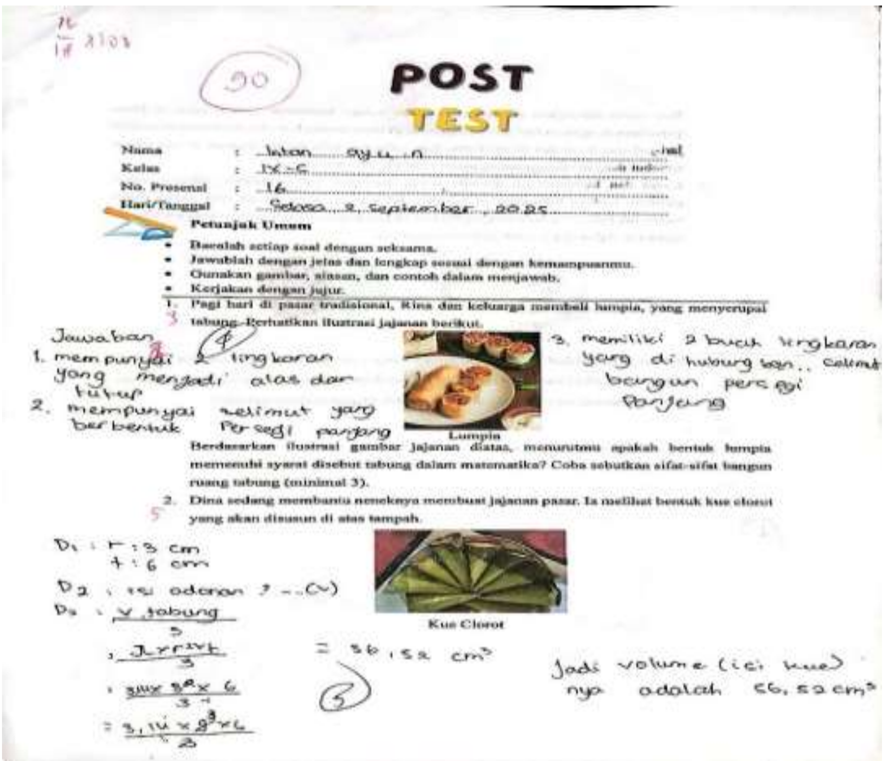
Table 8 <Categories of Student Self-Confidence>

Category	Number of Students	Percentage
High	3	12%
Moderate	20	80%
Low	2	8%

Most students (80%) fell into the moderate self-confidence category, with smaller proportions in the high (12%) and low (8%) categories.

Mathematical Understanding by Self-Confidence Category

Analysis of students' written test work across the three self-confidence categories showed a consistent pattern. Students with high self-confidence produced coherent, systematically ordered solutions and correctly identified the relevant concepts and formulas for curved-sided solids, though occasional errors persisted in the final arithmetic steps.



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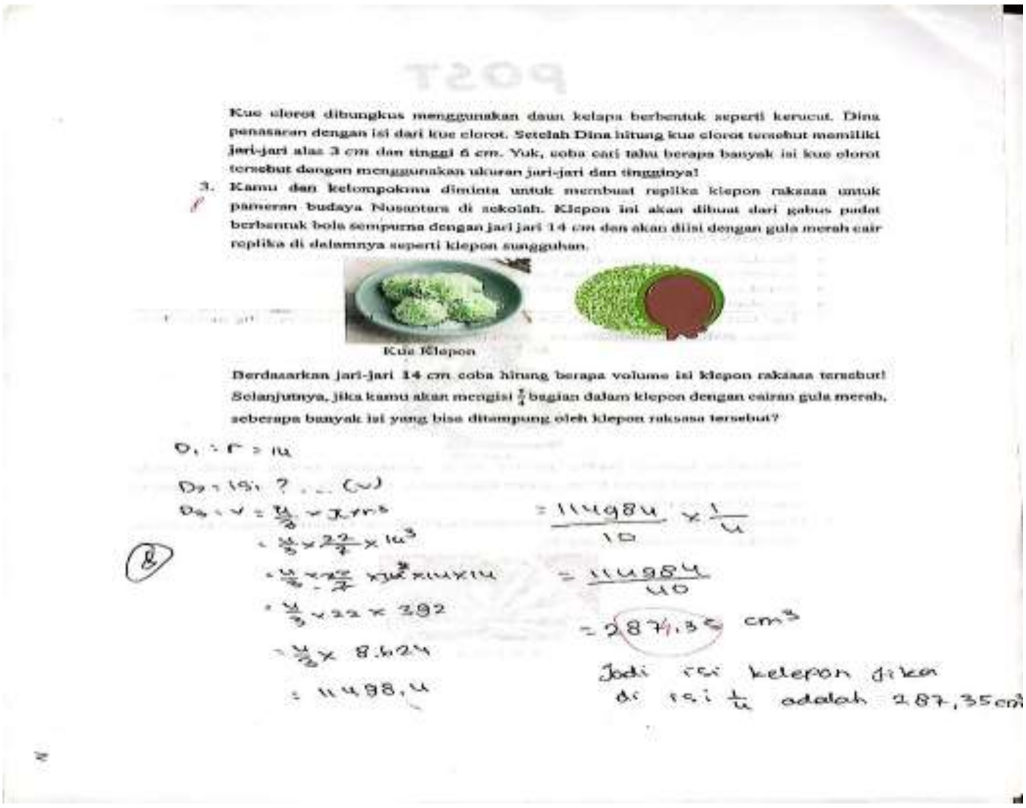

Figure 3<Example of Student Work High Self-Confidence Category>

Students with moderate self-confidence identified relevant information and began outlining solution steps, but these steps were not always fully coherent, and inaccuracies appeared in applying the correct formula; these students also tended to remain hesitant about explaining their reasoning aloud.

Students with low self-confidence had greater difficulty identifying key information and formulating accurate solution steps, produced more incomplete or unsystematic answers, and showed visible hesitation while working through problems; errors occurred both in calculation and in the application of basic concepts.

Interview Findings

Interviews with the six purposively selected students reinforced this pattern. A student in the high self-confidence category described how the visualization directly supported calculation:

> *S1: "With the POTRAME medium, I can see the shape of the three-dimensional figure directly, making it easier to understand how to calculate it."*

A student in the moderate self-confidence category reported that the visualization helped but did not fully resolve procedural uncertainty:

> *S3: "The POTRAME media helps me see the shapes of three-dimensional figures, but sometimes I'm still confused about determining the first step when working on a problem."*

A student in the low self-confidence category described a similar gap between visual understanding and confidence in applying it:

> *S5: "The shape of the solid is clearly visible, but I'm still unsure when working on the problem."*

Across the six interviews, students consistently reported that the AR visualization made the shapes easier to picture; the difference between categories concerned less what students could see and more how confidently they translated that visual understanding into a written solution procedure.

Students' mean scores rose from 14.31 at pretest to 74.96 at posttest, with a statistically significant paired-sample t-test result and an N-Gain of 0.71 (high category). Within the bounds of the one-group design used here, this pattern is consistent with the view that mathematical understanding develops through connecting new concepts to existing, related representations (Yang et al., 2021), and it is broadly consistent with prior evidence that AR-based media support geometric conceptual understanding (Beisenbayeva et al., 2024; Husna et al., 2025;

Nadzeri et al., 2024; Apriza et al., 2024). This is also consistent with the specific finding that POTRAME improved conceptual understanding of curved three-dimensional shapes in a comparable classroom setting (Dewi et al., 2025).

The size of the gain observed here is plausible in light of the broader literature on spatial visualization and mathematics achievement: a large-scale meta-analysis found a consistent positive association between spatial skill and mathematics performance (Atit et al., 2022), and more recent classroom studies using AR- and VR-based visualization tools report comparable increases in spatial-visualization performance following short instructional interventions (Medina Herrera et al., 2024). Interactive AR visualization of curved-sided solids likely supports understanding by letting students inspect the same object from multiple perspectives simultaneously with verbal explanation, reducing the cognitive burden of mentally constructing a three-dimensional model from a two-dimensional diagram (Kumalasari & Efendiy, 2025; Putri et al., 2025). This pattern is also broadly consistent with findings from GeoGebra-based visualization interventions in Indonesian geometry classrooms (Ayna & Sari, 2024) and with conceptual-understanding gains reported for other structured, activity-based mathematics interventions using one-group designs (Tonra et al., 2022; Alzanatul Umam & Zulkarnaen, 2022).

Beyond the cognitive outcome, this study examined students' self-confidence. Most students (80%) fell into the moderate category, and the pattern of test-work and interview evidence indicated that higher self-confidence was associated with more coherent, systematically organized problem-solving, while lower self-confidence was associated with continuing hesitation and less complete solutions, even when students reported that the AR visualization made the underlying shape easy to picture. This is consistent with scoping-review evidence that students' mathematics self-efficacy or self-confidence is closely tied to how persistently and systematically they engage with a task, independent of their conceptual grasp of the material (Street et al., 2024), and with prior findings linking self-confidence to stronger mathematical communication and problem-solving performance (Yuniarti et al., 2023; Wahyuni et al., 2024). Read together, these findings suggest that POTRAME's AR visualization primarily supported the perceptual and conceptual side of understanding seeing and grasping the shape while translating that understanding into a confidently executed written solution remained more strongly tied to students' pre-existing self-confidence, a pattern that has not, to our knowledge, been reported in prior POTRAME- or pop-up-book-based AR studies, which have generally evaluated cognitive outcomes alone (Dewi et al., 2025; Apriza et al., 2024; Nadzeri et al., 2024).

Limitations

Several limitations bound the interpretation of these findings. First, the one-group pretest-posttest design lacks a control or comparison group, so alternative explanations for the observed gain including maturation, repeated-testing effects, and the general instructional time devoted to the topic rather than the medium specifically cannot be ruled out. Second, the sample was a single, non-randomly-assigned class (n = 25) at one school, drawn through cluster random sampling from a single site; as discussed in the Method, a single-cluster design of this size does not provide adequate statistical power to detect small effects, nor does it allow between-cluster variability to be estimated, both of which limit the generalizability of the magnitude of the reported gain beyond this class (Li et al., 2024). Third, the four-session intervention was short, so any longer-term retention of the conceptual gains observed here remains untested. Fourth, self-confidence was treated here as a categorical grouping variable measured once, after instruction, rather than as a moderator or mediator tested through a pre-registered statistical model; the qualitative pattern reported above should accordingly be read as a descriptive association rather than a tested causal pathway. Taken together, these limitations mean the reported effectiveness of POTRAME should be treated as promising, exploratory evidence rather than as confirmed causal efficacy; the appropriate next step is a controlled comparison, discussed further below.

Conclusions

Within this exploratory, one-group pretest-posttest study, POTRAME-supported instruction was associated with a statistically significant and substantively large increase in students' mathematical understanding of curved-sided three-dimensional shapes, from a mean pretest score of 14.31 to a mean posttest score of 74.96 (N-Gain = 0.71, high category). This pattern is consistent with, though it does not on its own establish, a causal effect of the medium, since the design does not include a control group and therefore cannot separate the medium's contribution from maturation, testing effects, or general instructional time.

Beyond the cognitive outcome, the findings indicate that self-confidence played a distinct role: students with higher self-confidence tended to translate their visual understanding of the AR-rendered solids into more coherent, systematic written solutions, while students with lower self-confidence continued to hesitate and produce less complete solutions despite reporting that the visualization made the shapes easier to picture. This suggests that AR-based visualization media such as POTRAME may need to be paired with explicit affective scaffolding for example, structured opportunities for lower-confidence students to rehearse and present partial solutions rather than being treated as a sufficient intervention on their own.

Given the small, single-site sample and the absence of a control group, these results should be treated as preliminary rather than as established evidence of POTRAME's effectiveness, and any recommendation for broader classroom adoption should be qualified accordingly. Future research is therefore recommended to (1) replicate this study using a randomized or quasi-experimental control-group design with a total sample of at least 30 students per condition, ideally drawn from multiple classes or schools, to allow an adequately powered comparison (Li et al., 2024); (2) extend the intervention period beyond four sessions to assess retention of conceptual gains over time; (3) test self-confidence explicitly as a moderator of the medium's effect using a pre-registered statistical model rather than a purely descriptive category comparison; and (4) re-validate the self-confidence questionnaire in other school contexts to confirm that its psychometric properties generalize beyond the present sample.

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