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Development and evaluation of a cospaces edu-based virtual reality environment to support conceptual understanding of solid geometry

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Abstract

Background: Junior high school students often experience difficulties visualizing three-dimensional objects, distinguishing surface area from volume, and connecting two- and three-dimensional representations. However, evidence on CoSpaces Edu-based VR for supporting conceptual understanding of solid geometry remains limited.
Aims: This study aimed to develop and evaluate a CoSpaces Edu-based VR environment to support eighth-grade students' conceptual understanding of solid geometry.
Method: This Research and Development study employed the ADDIE model. The media was reviewed by two experts and piloted with 45 eighth-grade students selected through purposive sampling. Data were collected using expert validation sheets, a student response questionnaire, and six-item pretest and posttest instruments. Analyses assessed validity, student-perceived practicality, instrument reliability, and changes in conceptual understanding.
Results: The media obtained an average Aiken's V of 0.78, indicating very good validity, while student responses yielded a practicality score of 87.85%, categorized as very practical. The student response questionnaire showed high internal consistency (Cronbach's $\alpha = 0.94$), while the pretest and posttest yielded KR-20 coefficients of 0.68 and 0.60, respectively. The Wilcoxon signed-rank test showed a significant pretest–posttest difference ($p < 0.001$) with a large effect size ($r = 0.85$). The average normalized gain was 53.78%, indicating limited relative improvement.
Conclusion: The developed environment showed preliminary classroom usability and changes in conceptual-understanding scores, but the limited normalized gain indicates that conceptual improvement remained partial.

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INTRODUCTION

Learning solid geometry requires students to visualize and reason about three-dimensional objects represented in different forms. At the junior high school level, understanding solid geometry is important because it provides a foundation for learning three-dimensional geometry and developing spatial reasoning skills, including mental rotation and spatial visualization (Fujita et al., 2022). These abilities also contribute to students' mathematical performance across different content domains (Xu et al., 2025). Therefore, geometry instruction that engages students in visualizing and reasoning about three-dimensional objects can support deeper understanding beyond formula memorization.

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However, many students still experience difficulties in learning solid geometry. Although VR-based geometry learning has shown potential to support spatial understanding, students may still experience difficulties in identifying and relating components of three-dimensional objects (Herrera et al., 2024; Su et al., 2022). Instruction that emphasizes procedural calculation and formula memorization provides limited opportunities for conceptual exploration. Consequently, students may have difficulty connecting geometric concepts with real-world objects and may make conceptual and strategic errors that indicate limited understanding rather than weak computational skills (Shimizu & Kang, 2025).

Students' difficulties are particularly evident when they distinguish between surface area and volume or connect three-dimensional objects with two-dimensional representations, such as nets and projections (Elsa et al., 2022). Limited representational experience and differences in spatial cognitive development may cause students to rely on memorized procedures instead of meaningful geometric reasoning (Pertiwi et al., 2023). Previous research has also identified systematic errors in visualization, analysis, and deduction, indicating that students' visual, analytical, and logical skills are not yet adequately integrated in solid geometry learning (Hartati et al., 2024). These conditions indicate the need for learning media that support dynamic spatial exploration, as static representations may provide limited opportunities for students to examine relationships between two- and three-dimensional forms.

Empirical studies have shown that VR-based mathematics learning can support students' learning outcomes, conceptual understanding, and motivation in geometry. For example, (Su et al., 2022) reported better learning outcomes among students who used immersive VR to learn geometry than those who received paper-based instruction, while (Cevikbas et al., 2023) highlighted visualization, conceptual understanding, engagement, and motivation as important benefits of AR/VR use in mathematics education. These findings indicate that VR is particularly relevant for geometry learning because it provides opportunities to explore spatial relationships through interactive three-dimensional representations.

Previous studies have demonstrated the potential of immersive VR for geometry learning and have explored CoSpaces Edu in various educational contexts; however, the available evidence remains fragmented. VR-based geometry studies have primarily examined learning outcomes and spatial abilities, whereas studies involving CoSpaces Edu have often focused on broader educational applications or users' perceptions rather than its systematic use for supporting conceptual understanding of solid geometry (Berns et al., 2023; Rizky & Nurhamidah, 2024; Su et al., 2022). Consequently, empirical evidence remains limited regarding how a CoSpaces Edu-based VR environment can pedagogically integrate three-dimensional visualization and guided interaction to support junior high school students' conceptual understanding of solid geometry.

To address this empirical gap, this study investigated the development and evaluation of a CoSpaces Edu-based VR environment designed to support eighth-grade students' conceptual understanding of solid geometry through three-dimensional visualization and guided interaction. The study examined the environment in terms of its validity, practicality, and observed changes in students' conceptual understanding following classroom implementation. By doing so, the study provides empirical evidence on the pedagogical integration of CoSpaces Edu-based VR for conceptual learning in junior high school solid geometry, extending previous research that has largely examined VR-based geometry learning and CoSpaces Edu applications separately.

LITERATURE REVIEW

Virtual reality provides an interactive environment in which students can examine three-dimensional geometric representations from multiple perspectives. From the perspective of the

Cognitive Theory of Multimedia Learning, meaningful learning occurs when learners actively select, organize, and integrate relevant visual and verbal information (Mayer, 2024). In immersive environments, however, immersion alone does not necessarily lead to better learning; effective instructional design is needed to support cognitive processing and meaningful learning (Makransky & Mayer, 2022). These principles are particularly relevant to solid geometry, where students need to coordinate visual representations with conceptual information when reasoning about three-dimensional objects. Accordingly, a VR platform that combines spatial visualization, interaction, and structured instructional support may provide an appropriate environment for geometry learning.

Within this instructional perspective, CoSpaces Edu provides a VR-based learning environment that combines three-dimensional objects, animations, and interactive features, allowing students to explore geometric representations from multiple perspectives rather than viewing them only as static images (Berns et al., 2023). Its block-coding system can connect this immersive exploration with structured learning activities through interactive buttons, access to instructional materials, question-based interactions, and immediate feedback. These features are educationally relevant because they integrate dynamic spatial visualization with guided learning activities within the same virtual environment. Previous studies have also identified CoSpaces Edu as having potential to support interactive learning and computational thinking, although research has often focused more on user perceptions than on the systematic development of mathematics content (Rizky & Nurhamidah, 2024).

Research on VR-based geometry learning has demonstrated improvements in students' understanding of three-dimensional concepts. CoSpaces Edu also provides more extensive interactivity than learning applications with limited programming and animation features (Simbolon et al., 2025). Furthermore, the use of CoSpaces and related AR or VR tools has been associated with improvements in motivation, engagement, mathematical thinking, and spatial visualization. Taken together, these studies suggest that CoSpaces Edu may provide relevant interactive and spatial support for geometry learning, although its application to junior high school solid geometry requires further empirical investigation.

METHOD

Research Design

This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Khoirunnisya, 2023). The model was used to guide the systematic development of CoSpaces Edu-based virtual reality learning media for flat-sided solid geometry. The developed media integrated three-dimensional objects, interactive learning materials, adventure-based activities, contextual questions, and immediate feedback through block-based coding.

The Analysis stage identified students' learning needs and problems through a literature review, curriculum analysis, classroom observations, and teacher interviews. The Design stage involved preparing the learning flow, storyboard, interaction design, media interface, and research instruments. During the Development stage, the virtual environment, three-dimensional objects, animations, interactive buttons, and block-coded scripts were created and validated by experts. The Implementation stage involved a limited classroom trial, while the Evaluation stage examined the validity, practicality, and effectiveness of the developed media. The research framework is presented in Figure 1.

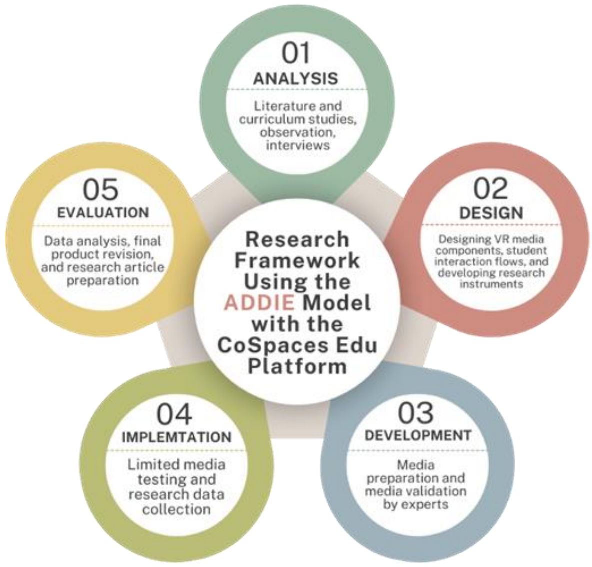


Figure 1. Research Framework Using the ADDIE Model with the CoSpaces Edu Platform

Participant

The study involved 45 eighth-grade students from SMPN 1 Wonorejo who participated in a limited-scale classroom trial. The students used the developed CoSpaces Edu-based VR environment to study solid geometry and completed the research instruments before, during, and after the learning activities. Given the relatively small sample drawn from a single school, the findings should be regarded as preliminary and context-specific rather than directly generalized to broader junior high school populations.

The accessible population consisted of eighth-grade students at SMPN 1 Wonorejo, from which 45 students were selected through purposive sampling for the limited-scale trial. Purposive sampling was used because participation required a specific eligibility criterion: students had not yet received formal classroom instruction on solid geometry, thereby reducing the influence of prior formal instruction when examining changes in conceptual understanding after the initial implementation of the VR environment. However, because the participants were selected based on a predefined criterion rather than random sampling, potential selection bias cannot be excluded, and the findings should be interpreted within the characteristics of the selected group.

The study employed expert validation sheets, pretest and posttest instruments, and a student response questionnaire. The expert validation involved two validators who independently assessed the content validity and instructional feasibility of the CoSpaces Edu-based VR environment across content, presentation, language, visual appearance, text readability, navigation, design consistency, and interactivity. Given the limited-scale developmental scope of the study, the two-expert evaluation was used as an initial expert-based assessment rather than as comprehensive evidence of content validity. Therefore, the validation findings should be interpreted within the limitation of the small expert panel.

The pretest and posttest each consisted of six four-option multiple-choice items designed to assess students' conceptual understanding of solid geometry. The items covered six aspects: identification of three-dimensional figures based on their characteristics, properties of solid figures, volume relationships in rectangular prisms, volume of pyramids, surface area of prisms, and the interpretation of two-dimensional nets as representations of three-dimensional objects. The pretest and posttest assessed comparable concepts using different but related questions to reduce the possibility that students merely recalled answers from the pretest. For example, one pretest item required students to determine the volume of a rectangular prism with dimensions of 12 cm × 6 cm

× 4 cm, whereas the corresponding posttest item required them to determine an unknown height from a given rectangular-prism volume, length, and width. Each item was scored dichotomously, with 1 assigned to a correct response and 0 to an incorrect response, resulting in a total raw score ranging from 0 to 6 for each test.

The student response questionnaire consisted of 15 items covering four aspects: format, content, language, and usefulness. Responses were scored using a four-point Likert scale: 1 for poor, 2 for fair, 3 for good, and 4 for very good. The scores obtained from the questionnaire were compared with the maximum possible scores and converted into percentages to determine the practicality of the media. The internal consistency of the six-item pretest and posttest was examined separately using the Kuder–Richardson 20 (KR-20) coefficient because the items were scored dichotomously. The internal consistency of the 15-item student response questionnaire was assessed using Cronbach's alpha. The reliability coefficients were calculated using responses from the 45 participants in the main classroom trial and are reported in the Results section.

Procedures

The study was conducted through the five stages of the ADDIE model, with each stage producing information or outputs that informed the subsequent stage.

1. Analysis. The researchers reviewed relevant literature and curriculum documents and conducted classroom observations and teacher interviews to identify students' difficulties in learning solid geometry, the learning resources commonly used in the classroom, the availability of learning media, and students' interest in technology-based learning. The findings from this stage were used to determine the instructional and technological requirements of the VR environment.
2. Design. Based on the identified needs, the researchers developed a storyboard and learning sequence specifying the organization of instructional content, student interaction flow, virtual environment layout, three-dimensional representations, learning activities, contextual questions, and assessment instruments. CoSpaces Edu was selected as the primary development platform because it enabled the construction of the three-dimensional virtual environment and block-coded interactions, while Canva was used to prepare instructional visual materials and Sketchfab to obtain and import three-dimensional models required for representing solid-geometry objects. This stage produced the initial instructional and interface design that guided the subsequent development of the VR environment.
3. Development. The initial design was transformed into an interactive CoSpaces Edu-based VR environment by integrating three-dimensional geometric models, instructional materials, animations, navigation elements, interactive activities, and block-coded feedback. The completed prototype was reviewed by two experts, whose feedback led to several revisions, including the addition and refinement of three-dimensional models, clearer instructional and navigation guidance, and the replacement of noncontextual questions with contextual geometry problems. The revised prototype was subsequently prepared for the limited-scale classroom implementation.
4. Implementation. The revised VR environment was implemented in a limited-scale classroom trial involving 45 eighth-grade students at SMPN 1 Wonorejo. Students completed the pretest before using the environment, participated in the VR-based learning activities, and subsequently completed the posttest and student response questionnaire.
5. Evaluation. Data obtained from expert validation, student responses, and pretest–posttest assessments were analyzed to examine the validity and practicality of the developed environment and the observed changes in students' conceptual understanding. The evaluation results were also used to identify aspects requiring further refinement.

Analysis Plan

The analysis addressed three components: product validity, student-perceived practicality, and changes in students' conceptual understanding. Product validity was examined using Aiken's V, while practicality was summarized using percentage scores from the student response questionnaire. Changes in students' conceptual understanding were evaluated using paired pretest–posttest comparisons, normalized gain, and an effect-size measure to describe the magnitude of the observed change.

1. Product Validity Analysis

   Product validity was assessed using Aiken's V to quantify expert-based content validity of the developed VR environment (Retnawati, 2016). Because Aiken's V provides evidence based on expert judgment rather than comprehensive evidence of measurement quality, the internal consistency of the student-measurement instruments was examined separately. KR-20 was used for the dichotomously scored pretest and posttest, whereas Cronbach's alpha was used for the student response questionnaire.

$$V = \frac{\sum s}{[n(c-1)]}$$

where:

$$s = r - L_o$$

Descriptions:
V : Aiken index validity
n : Number of validators (assessors)
c : Highest assessment score
L_o : Lowest assessment score
r : Score given by the validators

The resulting Aiken's V scores were interpreted using the criteria presented in Table 1 (Mansur et al., 2023).

Table 1. Classification of Aiken's V Validity Levels.

Interval Score	**Level**
$0.76 < V \leq 1.00$	Very Good
$0.59 < V \leq 0.76$	Good
$0.41 < V \leq 0.59$	Pretty Good
$0.24 < V \leq 0.41$	Not Good

2. Product Practicality Analysis

   Product practicality was evaluated using two complementary sources of evidence: a 15-item student response questionnaire and classroom teacher observation during the implementation of the VR environment. The questionnaire assessed students' perceptions of the format, content, language, ease of use, and usefulness of the environment, and the resulting scores were converted into percentages.. Teacher observation was used as supplementary qualitative evidence, focusing on students' participation during the learning activities and their apparent responsiveness to the solid-geometry content presented through the VR environment. The questionnaire results and teacher observations were interpreted together to provide a more comprehensive assessment of the practicality of the developed environment:
   (Parapat & Sagala, 2022):

$$Practicality\ Scores = \frac{\sum Scores\ Obtained}{\sum Maximum\ Score} \times 100\%$$

The percentage scores were interpreted according to the criteria presented in Table 2.

Table 2. Product Practicality Criteria

Practicality Percentage	Category
85.01%–100.00%	Very practical; the product can be used without revision
70.01%–85.00%	Reasonably practical; the product can be used with minor revision
50.01%–70.00%	Not practical; substantial revision is required
1.00%–50.00%	Not practical; the product should not be used

3. Product Effectiveness Analysis

Changes in students' conceptual understanding were examined using paired pretest and posttest scores. The Shapiro–Wilk test was used to assess score distribution, followed by the Wilcoxon signed-rank test to examine differences between the paired scores at a significance level of 0.05. The magnitude of the pretest–posttest difference was further estimated using effect size r, calculated from the Wilcoxon test statistic. Normalized gain was also calculated to describe the relative improvement in students' conceptual understanding from pretest to posttest (Amijaya et al., 2024). The resulting normalized gain was interpreted according to the criteria presented in Table 3 adapted from (Fricker et al., 2023).

$$N - gain = \frac{Posttest\ Score - Pretest\ Score}{Maximum\ Score - Pretest\ Score}$$

The criteria for assessing the effectiveness of the N-gain score can be based on its percentage value (%). The categorization of N-gain effectiveness is shown in Table 3 (Fricker et al., 2023).

Table 3. N-Gain Effectiveness Categorie

N-Gain Percentage	Category
$\leq 40\%$	Ineffective
$40\% - 55\%$	Less Effective
$56\% - 75\%$	Effective
$\geq 76\%$	Very Effective

RESULTS AND DISCUSSION

Results

Analysis Stage

The analysis indicated that students had difficulty understanding several aspects of solid geometry. Classroom observations and teacher interviews at SMPN 1 Wonorejo showed that instruction was predominantly lecture-based and relied mainly on textbooks, worksheets, and simple physical models. Students particularly experienced difficulties in distinguishing surface area from volume and in connecting two-dimensional representations with three-dimensional objects. The analysis also indicated that students had limited experience exploring three-dimensional objects interactively, despite showing interest in visual and technology-based learning media.

Design Stage

The Design stage resulted in an instructional structure for GeoLand that organized students' interactions with the VR environment into a sequential learning flow. As shown in Figure 2, students entered the environment, accessed instructional materials, explored three-dimensional geometric objects, participated in interactive activities, answered contextual questions, and received feedback before reflecting on the learning outcomes. This structure integrated content exploration, spatial interaction, and question-based activities within a single learning sequence that served as the blueprint for the subsequent development of the GeoLand environment.

Figure 2. Student Interaction Diagram in CoSpaces Edu VR Media

Development Stage

During the Development stage, the storyboard was transformed into the interactive GeoLand VR environment. The developed environment integrated three-dimensional geometric representations, instructional materials, navigation features, adventure-based activities, contextual questions, and immediate feedback. Figure 3 presents the developed GeoLand environment, illustrating the overall virtual setting and the entry point to the adventure-based learning activities.

(a)

Translation: QUIZ GEOLAND Let's explore the world of GeoLand and discover the items below!!! Good luck	Hello GeoLand Friends!!! Are you ready to start your adventure? If you're ready, click START BOARD on my right!!!

(b)

Figure 3. GeoLand VR Environment: (a) Overall View and (b) Adventure-Quiz Opening Screen

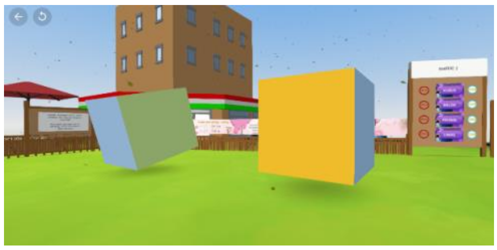
The completed prototype was independently reviewed by two experts across visual appearance, text readability, navigation, design consistency, interactivity, and attractiveness. Aiken's V coefficients were calculated to summarize the level of agreement between the two experts, as presented in Table 4.

Table 4. Expert Validation Results for the CoSpaces Edu-Based VR Learning Media

Item	Lecturer 1 Scores	Lecturer 2 Scores	$\sum s$	V
1	3	4	5	0.83
2	2	4	4	0.67
3	3	3	4	0.67
4	4	3	5	0.83
5	3	4	5	0.83
6	4	3	5	0.83
7	3	4	5	0.83
8	4	4	6	1.00
9	3	3	4	0.67
10	4	2	4	0.67
Average				0.78

The average Aiken's V coefficient was 0.78, which fell within the very good category according to the predetermined criteria. Given the limited two-expert panel, this result was interpreted as preliminary expert-based evidence supporting the content and instructional suitability of the GeoLand environment rather than as comprehensive validation. The expert ratings were therefore considered together with their qualitative recommendations to guide revisions before classroom implementation.

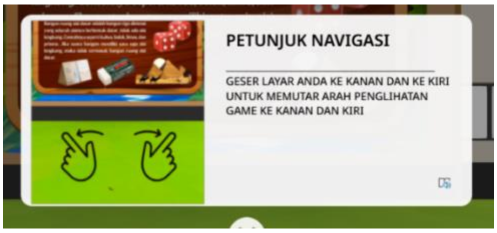
More specifically, Items 2, 3, 9, and 10 obtained relatively lower Aiken's V coefficients of 0.67, indicating areas that required further refinement in navigation, visual support for conceptual understanding, instructional clarity, and language accuracy. In response to the expert feedback, navigation and instructional cues were clarified, three-dimensional representations were added and refined to provide more complete visual support for solid-geometry concepts, and textual elements were reviewed to improve clarity and linguistic accuracy. The experts also recommended replacing several direct, noncontextual questions with contextual geometry problems to make the learning activities more meaningful. These revisions were intended to strengthen the instructional clarity, visual completeness, navigational usability, and contextual relevance of the GeoLand environment before classroom implementation. The major revisions implemented in response to the experts' feedback are illustrated in Figure 4.

Item	Before	After
A		

B

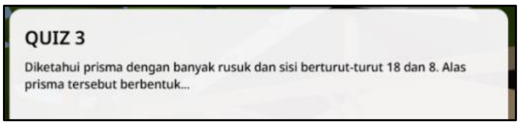
English translation: After studying all the material, let's play with GeoLand! Follow the directions on the signboard on the side to find the playing location!

C



English translation: "NAVIGATION INSTRUCTIONS" Swipe your screen right and left to turn the game's view to the right and left.

D



English translation: QUIZ 3
Given a prism with 18 edges and 8 faces. The prism is shaped like.....

English translation: QUIZ 4
Lina bought a rectangular gift box for her friend's birthday. The box is 20 cm long, 12 cm wide, and 10 cm high. Lina wants to wrap the entire surface of the box with wrapping paper without leaving any part exposed. What is the minimum area of wrapping paper Lina needs to wrap the entire surface of the box?

Figure 4. Major Revisions to the GeoLand Environment Following Expert Validation: (A) Three-Dimensional Representations, (B) Instructional Guidance, (C) Navigation Guidance, and (D) Contextualization of Learning Questions

Implementation Stage

The revised media was implemented in a limited-scale trial involving 45 eighth-grade students at SMPN 1 Wonorejo. Students completed a pretest, used the media to explore three dimensional objects and answer interactive questions, and then completed a posttest. The comparison between students' pretest and posttest scores is presented in Figure 5.

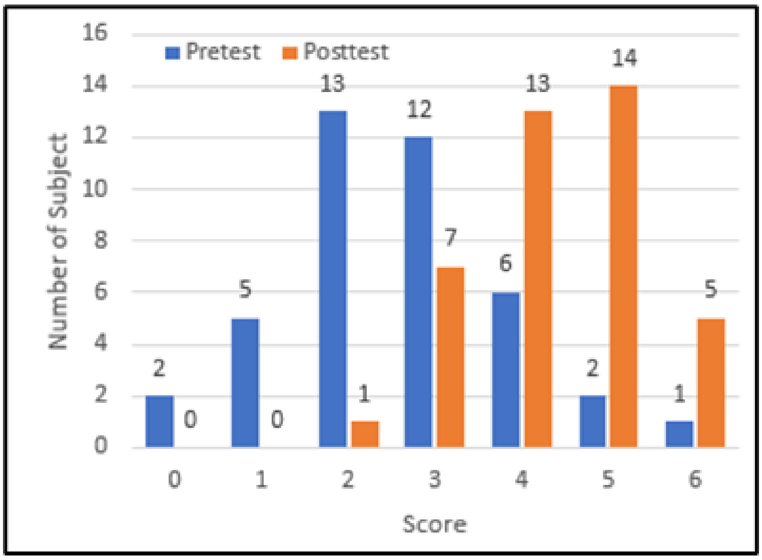


Figure 9. Comparison of Students' Pretest and Posttest Scores

After the learning activities, students completed a 15-item response questionnaire covering format, content, language, and usefulness. The questionnaire yielded a total score of 2.372 out of a maximum score of 2.700, corresponding to 87.85%. Based on the predetermined criteria, this score indicated a very high level of practicality from the students' perspective, as presented in Table 5.

Table 5. Student Response Questionnaire Results

No	Assessed Aspect	Question Item	Score		Percentage	Description
			Result	Expectation		
1	Format	5	2,372	2,700	87.85%	Very Practical
2	Content	3				
3	Language	5				
4	Uses	2				

The 15-item student response questionnaire demonstrated high internal consistency, with a Cronbach's alpha coefficient of 0.94 based on responses from the 45 participating students. This coefficient indicates that the questionnaire items showed a high degree of consistency in measuring students' perceptions of the GeoLand environment. Therefore, the questionnaire results were considered sufficiently consistent for interpreting student-perceived practicality.

Teacher observation during the classroom implementation provided complementary evidence to the questionnaire results. The classroom teacher observed that students who typically showed limited participation during regular mathematics instruction became more actively involved when using the GeoLand environment, particularly when exploring three-dimensional objects, responding to questions, and participating in the learning activities. The teacher also perceived that students followed the solid-geometry content more readily than during the instructional approach usually employed in the classroom, especially when concepts were presented through three-dimensional visual representations. These observations provided complementary qualitative evidence regarding the classroom practicality of the GeoLand environment.

Evaluation Stage

Before examining changes in students' conceptual understanding, the internal consistency of the six-item pretest and posttest was evaluated using responses from the 45 participating students. The pretest yielded a KR-20 coefficient of 0.68, while the posttest yielded a KR-20 coefficient of 0.60. These coefficients were considered when interpreting the subsequent pretest–posttest analyses.

Following the reliability analysis, the distribution of the pretest and posttest scores was examined using the Shapiro–Wilk test to determine the appropriate statistical procedure for comparing the paired scores. The results are presented in Table 6.

Table 6. Shapiro–Wilk Normality Test Results

Test	W	df	p	Interpretation
Pretest	0.896	45	<0.001	Non-normal
Posttest	0.906	45	0.001	Non-normal

As shown in Table 6, the pretest yielded a Shapiro–Wilk statistic of $W = 0.896$, $df = 45$, and $p < 0.001$, while the posttest yielded $W = 0.906$, $df = 45$, and $p = 0.001$. Both p-values were below the 0.05 significance level, indicating that the pretest and posttest scores deviated significantly from a normal distribution. Therefore, the paired scores were subsequently analyzed using the Wilcoxon signed-rank test. Because the score distributions did not meet the normality assumption, the paired pretest and posttest scores were compared using the Wilcoxon signed-rank test. The results, including the rank distribution and effect-size estimate, are presented in Table 7.

Table 7. Wilcoxon Signed-Rank Test Results for Pretest and Posttest Scores

Comparison	Positive Ranks	Negative Ranks	Ties	Z	p	Effect Size (r)
Posttest-pretest	42	1	2	-5.678	<0.001	0.85

As shown in Table 7, 42 students obtained higher posttest scores, one student obtained a lower score, and two showed no change. The Wilcoxon signed-rank test indicated a statistically significant difference between the paired pretest and posttest scores ($Z = -5.678, p < 0.001$). The corresponding effect size was $r = 0.85$, indicating a large magnitude of the observed pretest–posttest difference. These results therefore indicate a statistically significant and substantial change in students' conceptual-understanding scores following the implementation of the GeoLand environment. Normalized gain was subsequently calculated to describe the relative improvement in students' conceptual-understanding scores. The result is presented in Table 8.

Table 8. Normalized Gain of Students' Conceptual Understanding

Measure	Value
Average normalized gain	0.5378
Percentage	53.78%

As shown in Table 8, the average normalized gain was 0.5378, equivalent to 53.78%, indicating that the relative magnitude of improvement remained limited. This result should be distinguished from the Wilcoxon finding and its effect size: the Wilcoxon test showed that the direction of score change was statistically significant ($p < 0.001$), with a large rank-based effect size ($r = 0.85$), whereas normalized gain indicated that students achieved only part of the maximum improvement available from their initial scores. The present study did not directly examine the factors responsible for this limited gain; however, the expert evaluation identified instructional guidance, navigation, visual representation, and the contextualization of questions as areas requiring refinement before implementation. These aspects may have influenced how fully students could benefit from the VR environment and therefore warrant further investigation in subsequent implementations.

Discussion

The expert-validation findings are pedagogically relevant because the aspects identified for refinement were directly related to how students access and process spatial and conceptual information within the VR environment. Clearer instructional and navigation cues may help direct students' attention toward relevant learning information and reduce extraneous processing demands, which is consistent with the Cognitive Theory of Multimedia Learning (Makransky & Mayer, 2022; Mayer, 2024). Similarly, refined three-dimensional representations and contextualized questions may strengthen connections between visual representations, spatial relationships, and geometric concepts, which is particularly relevant to students' difficulties in coordinating two- and three-dimensional representations (Elsa et al., 2022; Pertiwi et al., 2023). Thus, the validation findings suggest that the quality of a VR learning environment depends not only on its technological interactivity but also on the clarity and pedagogical organization of its visual and instructional components.

The practicality score of 87.85% indicates that students generally perceived the GeoLand environment positively in terms of its format, content, language, and usefulness. This finding should be interpreted as evidence of user-perceived practicality rather than educational effectiveness. Teacher observation provided complementary qualitative evidence. Students who typically showed limited participation during regular mathematics instruction were observed to become more actively involved in exploring three-dimensional objects, responding to questions, and participating in learning activities. The teacher also perceived that students followed the solid-geometry content more readily when three-dimensional representations were available. However, this observation should not be considered a direct measure of conceptual improvement.

The present findings can be compared with previous research, although the evidence differs in scope and measurement. (Cevikbas et al., 2023) identified visualization, engagement, motivation, and conceptual learning as important benefits associated with AR and VR applications in mathematics education. (Su et al., 2022) provided more specific evidence from geometry learning, reporting favorable technology acceptance and stronger learning motivation among students using immersive VR. Unlike these studies, the present study did not measure technology acceptance, motivation, or engagement as separate constructs. Its practicality evidence was based on student responses and complementary teacher observation during a limited classroom implementation. Therefore, the findings support the classroom usability and acceptability of GeoLand, while its contribution to conceptual understanding should be evaluated separately through the learning-outcome measures.

The observed pretest–posttest difference, accompanied by a large rank-based effect size ($r = 0.85$), indicates a substantial change in students' conceptual-understanding scores following the GeoLand implementation. This pattern may be interpreted through the Cognitive Theory of Multimedia Learning, which emphasizes the active selection, organization, and integration of relevant visual and verbal information (Mayer, 2024). GeoLand combined three-dimensional representations with instructional information and guided interaction, providing multiple forms of representation for reasoning about solid-geometry concepts. This interpretation is also consistent with previous evidence that immersive VR can support geometry learning when visualization and interaction are accompanied by appropriate instructional design (Makransky & Mayer, 2022; Su et al., 2022). However, because the study did not directly examine the learning mechanisms involved, these features should be regarded as theoretically plausible supports rather than demonstrated causes of the observed score changes.

Despite the substantial rank-based difference, the normalized gain of 53.78% indicates that the relative improvement did not reach the predetermined effectiveness threshold used in this study. This finding is particularly important because students reported high practicality and the teacher observed more active classroom participation. These results suggest that positive usability and participation did not automatically correspond to equally strong gains in conceptual understanding. One possible interpretation is that the instructional organization of the immersive environment remains important for supporting deeper conceptual learning. This interpretation is consistent with the expert validation, which identified instructional clarity, visual support, navigation, and the contextualization of questions as areas requiring refinement. Therefore, further development should focus specifically on improving these identified aspects rather than simply adding more technological features to the environment.

Implications

The findings provide a pedagogical implication that extends beyond the use of CoSpaces Edu as a technological platform. The expert-validation findings suggest that three-dimensional representations should be accompanied by clear instructional guidance, understandable navigation, and contextually meaningful questions to support students' interaction with solid-geometry concepts. This emphasis on the organization of visual and instructional information is consistent with multimedia learning principles, which highlight the importance of guiding learners in selecting, organizing, and integrating relevant information (Mayer, 2024).

The combination of high student-perceived practicality, more active classroom participation as observed by the teacher, and a normalized gain of 53.78% also provides an important implication for VR-based mathematics learning. Positive usability and participation should not be assumed to produce equally strong conceptual learning outcomes. Instead, the findings suggest that immersive features and instructional design should be evaluated as related but distinct components of the learning environment. This interpretation supports the view that the pedagogical value of VR depends on how its interactive and visual affordances are structured to support cognitive processing rather than on immersion alone (Makransky & Mayer, 2022).

Limitations and Suggestions for Future Research

This study has several methodological limitations that should be considered when interpreting the findings. The limited-scale trial involved 45 eighth-grade students selected purposively from a single school, making the findings context-specific and potentially limiting their transferability to other student populations and school settings. The purposive sampling procedure may also have introduced selection bias because participants were selected according to predefined eligibility criteria rather than through random sampling. In addition, the one-group pretest–posttest design did not include a comparison group, so the observed changes in students' conceptual-understanding scores cannot be attributed solely to the GeoLand environment. The findings should therefore be interpreted as preliminary evidence of changes following the implementation rather than as causal evidence of intervention effectiveness. The use of only two expert validators also limits the breadth of the content-validity evidence and should be regarded as an initial expert-based evaluation.

Future studies should evaluate GeoLand across multiple schools with more diverse student samples and include a comparison group receiving regular instruction. This would allow the transferability of the findings to be examined and provide stronger evidence regarding whether the observed changes differ from those under regular instruction. Further development should focus on the instructional components identified through expert validation, particularly navigation clarity, visual support, instructional guidance, and the contextualization of questions. Given that high student-perceived practicality and more active classroom participation coexisted with a normalized gain of 53.78%, subsequent research should specifically examine whether refinements to these components are associated with stronger conceptual-understanding outcomes. Such investigations could clarify which instructional design elements are most closely associated with conceptual learning in VR-based solid geometry.

CONCLUSION

This study developed and evaluated GeoLand, a CoSpaces Edu-based VR environment that integrates three-dimensional visualization and guided interaction for junior high school solid geometry. Expert evaluation and student responses indicated that the environment was suitable and generally usable during the limited classroom implementation, although these product-quality findings should not be interpreted as evidence of educational effectiveness. The pretest–posttest findings showed changes in students' conceptual-understanding scores, but the normalized gain of 53.78% did not reach the predetermined effectiveness threshold, indicating that the relative conceptual improvement remained partial. Accordingly, the findings provide preliminary empirical evidence for the classroom implementation of CoSpaces Edu-based VR while showing that positive usability and participation do not necessarily correspond to equally strong conceptual gains. The study therefore highlights the importance of integrating three-dimensional visualization and interactive features with structured instructional design when using VR to support conceptual learning in solid geometry.

AUTHOR CONTRIBUTIONS STATEMENT

Habibillah Achmad Putra Fauzi contributed to the conceptualization, research design, media development, instrument preparation, data collection, data analysis, visualization, and preparation of the original manuscript. Tatag Yuli Eko Siswono contributed to the conceptualization, research methodology, supervision, interpretation of the findings, and critical review of the manuscript. Nurus Saadah contributed to the research methodology, instrument and media validation, interpretation of the findings, and review and editing of the manuscript. Nonik Indrawatiningsih contributed to the research methodology, supervision, validation, interpretation of the findings, and review and editing of the manuscript. All authors read and approved the final version of the manuscript.

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