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Enhancing Conceptual Understanding in Geometry of Curved Solids: A Constructivist Philosophy Approach through Interactive E-Module for Secondary School Students

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ABSTRACT

Conceptual understanding is a crucial aspect of mathematics learning. However, in practice, students' mathematical conceptual understanding often tends to be low. One potential solution is the implementation of an interactive e-module grounded in constructivist philosophy to facilitate deeper understanding of mathematical concepts. This study aims to examine the influence of using a constructivist-philosophy-based interactive e-module on students' conceptual understanding in geometry of curved solids at the secondary school level. The research employed a quantitative quasi-experimental approach with a pretest–posttest non-equivalent control group design. The participants consisted of 62 ninth-grade students from a public junior secondary school in Boyolali Regency, Indonesia, who were divided into experimental and control groups. Data were collected using a conceptual understanding test that was validated and demonstrated good reliability (Cronbach's $\alpha = 0.82$). Data analysis was conducted using descriptive and inferential statistics. The Mann–Whitney U test revealed a significant difference in post-test scores between the experimental and control groups ($p < 0.001$), with the experimental group achieving a higher median score (75) than the control group (55.5). The effect size analysis indicated a strong practical effect ($r = 0.77$), suggesting that the observed difference was not only statistically significant but also educationally meaningful. These findings indicate that the constructivist-philosophy-based interactive e-module was effective in supporting the enhancement of students' conceptual understanding of geometry of curved solids. Furthermore, students who learned the material using the e-module demonstrated significantly better conceptual understanding than those who did not. These findings can serve as a reference for teachers in selecting appropriate digital learning media, while also contributing to the development of mathematics learning innovations oriented towards constructivism.

Keywords: Conceptual Understanding, Constructivist Philosophy, Geometry of Curved Solids, Interactive E-Module, Mathematics

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INTRODUCTION

Mathematical conceptual understanding is a fundamental ability that students, particularly junior high school students, need to master in mathematics learning (Kholid et al., 2021). Conceptual understanding refers to an individual's capacity to comprehend, internalize, and connect mathematical concepts to apply them in diverse situations (Perry & Len-Ríos, 2019; Sengkey et al., 2023). According to Indonesian Minister of Education and Culture Regulation Number 58 of 2014, understanding concepts is the primary objective students must achieve in the mathematics learning process (Mendikbud RI, 2014). This indicates that conceptual understanding is not only a prerequisite for solving mathematical problems but also forms the foundation for developing higher-order thinking skills (Nurhidayat et al., 2023). Strong conceptual understanding enables students to grasp the essence of learning materials profoundly and build a robust foundation for achieving mathematics learning objectives at subsequent educational levels (Kastira & Irwan, 2023; Nasution & Hafizah, 2020). Furthermore, students with sound conceptual understanding can recall, comprehend, apply, and modify concepts to solve varied problems and mathematical tasks (Lisnani, 2019). Therefore, students require strong conceptual understanding to think rationally, logically, and systematically in solving mathematical problems, and to connect learned concepts with contextual phenomena encountered in daily life. One mathematics topic demanding strong conceptual understanding is geometry of curved solids.

Geometry of curved solids, a branch of spatial geometry, involves solids with at least one curved surface (Marasabessy et al., 2021). In primary and secondary education in Indonesia, particularly secondary school, the geometry of curved solids studied include cylinders, cones, and spheres (Kemendikbudristek, 2024; Mendikbud RI, 2018). Learning geometry of curved solids serves as a means for students to develop analytical and interpretive skills for daily life phenomena while aiding their comprehension and application of other mathematical concepts (Özerem, 2012). Thus, students need to enhance their understanding of geometry of curved solids concepts and possess adequate skills to connect them with other geometry topics. However, students' conceptual understanding of geometry of curved solids is frequently found to be low (Özerem, 2012; Solin et al., 2023).

This assertion is corroborated by findings from Sudirman et al. (2023) and Isharyadi & Nurjanah (2025), which indicate that a significant number of secondary school students in Indonesia encounter difficulties in learning geometry, particularly regarding topics involving three-dimensional objects. These challenges stem from the abstract nature of the material, which demands high levels of spatial visualization and conceptual reasoning. Furthermore, students often struggle to articulate geometric concepts using their own words, identify the defining properties of geometry of curved solids, and apply appropriate procedures to solve geometric problems (Aprilia et al., 2024).

According to Gebremeskel et al. (2025), these issues are largely attributed to conventional instructional practices, such as the lecture method, which often fail to engage students actively in the learning process. Additionally, the instructional media and materials employed are predominantly manual and lack support from adequate interactive technology to visualize abstract concepts (Kuzle et al., 2023). These conditions contribute to the low conceptual understanding of students regarding geometry of curved solids. Consequently, the low level of students' mathematical conceptual understanding, specifically in the topic of geometry of curved solids, represents a critical issue that necessitates serious attention.

Low conceptual understanding can be addressed through electronic-based teaching materials (Hariyono & Ulia, 2020; Pujiastuti & Fitriah, 2019; Putri et al., 2021). One form of such materials is electronic modules (e-modules). An e-module is an electronic teaching resource integrating multimedia elements and interactive features to enhance learning experiences (Mariskha et al., 2022; Vrcek & Magdalenic, 2011). As part of electronic-based e-learning, e-modules utilize technological advancements through electronic devices in instruction (Ramadanti et al., 2021). Compared to printed modules, e-modules offer advantages in presenting content via video, audio, animation, and other interactive elements accessible repeatedly by students, providing a deeper learning experience (Holisoh et al., 2023; Suarsana & Mahayukti, 2013). Moreover, e-modules effectively enhance students' conceptual understanding in mathematics (Liyah et al., 2023; Ramli, 2022). To optimize the impact of e-modules on conceptual understanding, especially for abstract topics like curved solids, e-modules must be designed and developed in alignment with appropriate learning approaches (Ramli, 2022). A relevant approach in this context is one grounded in constructivist philosophy.

From a theoretical perspective, the constructivist philosophy, specifically Bruner's (1961) theory of guided discovery learning, emphasizes that students actively construct mathematical concepts through structured exploration and the use of progressively developing representations, rather than passively receiving information from the teacher (Febrianti & Purwaningrum, 2021). The instructional process is designed to transition from contextual experiences to visual representations, and subsequently to formal symbolic understanding.

These principles are underpinned by Piaget's (1972) cognitive constructivism, which views learners as active constructors of knowledge, as well as the concept of scaffolding rooted in social constructivism to guide students' conceptual development. In mathematics education, particularly concerning geometry of curved solids, constructivist-oriented learning is highly relevant as it requires students to visualize abstract three-dimensional objects, explore spatial relationships, and construct meaning through interaction with dynamic representations (Dogruer & Akyuz, 2020; Žakelj & Klančar, 2022). Therefore, the e-module developed based on the constructivist philosophies of Bruner and Piaget is expected to effectively support students' conceptual understanding of geometry of curved solids by facilitating active exploration, guided discovery, and meaningful learning experiences.

Several studies have examined the use of interactive e-modules in learning, employing various pedagogical approaches and disciplinary contexts. For instance, Sugiani et al. (2019) studied the effect of interactive e-modules with a constructivist blended learning approach on student learning independence. Rochsun & Agustin (2020) developed contextually-based mathematical problem e-modules to enhance student engagement, while Aulia & Prahmana (2022) emphasized realistic mathematics and mathematical literacy in e-module development. Other studies have reported the effectiveness of interactive e-modules in improving general learning outcomes (Darpiyah & Sulastri,

2023) or have applied constructivist-based e-modules in non-mathematical disciplines, such as biology (Maglinte & Coronica, 2023), as well as in different mathematical topics, such as two-variable linear equation systems (Pasaribu et al., 2024).

Although previous studies have demonstrated the pedagogical potential of interactive e-modules in educational settings, the majority have focused on general learning outcomes, student engagement, or learning independence. These studies have yet to explicitly examine how the philosophical principles of constructivism are operationalized to support the construction of students' conceptual understanding in geometry instruction. Specifically, empirical research investigating the effect of interactive e-modules based on constructivist philosophy on students' conceptual understanding of curved surface geometry at the secondary school level remains limited. Given the abstract nature of curved surface solids, which necessitates robust spatial visualization abilities and strong conceptual reasoning, further research is required to explore how constructivist-oriented interactive e-modules can effectively enhance students' conceptual understanding of this material. This study not only contributes to the development of technology-based electronic instructional materials but also strengthens the philosophical foundation of learning that promotes the construction of meaning and a deep understanding of concepts.

Based on this rationale, the research problem is: How does an interactive constructivist philosophy-based e-module influence the enhancement of students' mathematical conceptual understanding of curved solids? Accordingly, the study aims to examine the effect of using an interactive constructivist-based e-module on secondary school students' mathematical conceptual understanding of curved solids. The proposed hypothesis is that students learning geometry of curved solids using the interactive constructivist-based e-module will demonstrate better mathematical conceptual understanding compared to those learning without it.

METHOD

Research Design

This study employed a quantitative quasi-experimental approach with a pretest-posttest non-equivalent control group design (Creswell & Creswell, 2017; Miller et al., 2020). This design enabled the researchers to examine the effect of using an interactive constructivist philosophy-based e-module on students' mathematical conceptual understanding of curved solids. Figure 1 illustrates the research design implemented in this study.

Experimental Class	: P_1	X	Q_1

Control Class	: P_2	(-)	Q_2

Notes:

P_1 and P_2	: Pre-test
Q_1 and Q_2	: Post-test
X	: Implementation of Interactive E-Module
(-)	: No treatment
--------------	: Subjects were not selected randomly

Figure 1. Research Design

Within this design, two groups were utilized: an experimental class and a control class. The experimental class received the treatment, which involved learning curved solids material using the interactive constructivist philosophy-based e-module. Conversely, the control class underwent the same learning process without the e-module, relying solely on conventional textbooks as the primary learning resource. Furthermore, this study involved two variables: the independent variable (the interactive constructivist philosophy-based e-module) and the dependent variable (students' mathematical conceptual understanding ability).

Furthermore, the interactive e-module grounded in constructivist philosophy employed in this study was a product of research and development, having undergone validation and been deemed suitable for instructional use. The present study focused specifically on the Implementation phase to examine the effectiveness of the e-module in enhancing students' mathematical conceptual understanding.

Participants

The study population comprised all Grade IX students at one of Secondary School in Boyolali Regency. Sampling was conducted using the convenience sampling technique via intact class assignment, a method commonly employed in quasi-experimental educational research when random assignment is not feasible (Creswell & Creswell, 2017). Two existing classes—Class IX A (30 students) and Class IX B (32 students)—were selected based on school administrative considerations and scheduling constraints, rather than students' prior academic abilities. To mitigate potential selection bias inherent in non-random group assignment, a pre-test on mathematical conceptual understanding was administered to both classes prior to the intervention. This initial test aimed to verify baseline equivalence between the experimental and control groups before the treatment was administered. Following this procedure, Class IX A was designated as the experimental group and Class IX B as the control group.

Instruments

The research instrument consisted of a mathematical conceptual understanding test. The test comprised five essay questions divided into two parts: a pre-test and a post-test. Both the pre-test and post-test contained mathematically equivalent problems. The questions were developed based on indicators of conceptual understanding, as presented in Table 1. Prior to data collection, the instrument was validated by two expert validators in mathematics education.

Table 1. Conceptual Understanding Indicators (Sumarmo, 2014)

Student's Skill	Indicators
Conceptual Understanding	1. Rearticulating a concept in one's own words 2. Grouping or categorizing objects based on specific characteristics 3. Identifying appropriate and inappropriate examples of a concept 4. Representing a concept using various mathematical forms (e.g., symbols, diagrams, etc.) 5. Formulating necessary and/or sufficient conditions related to a concept 6. Applying, adapting, and choosing suitable procedures or operations 7. Utilizing concepts or algorithms in problem-solving contexts

Subsequently, the validators' assessments were analyzed using Cohen's Kappa inter-rater reliability test to measure the level of agreement between them (McHugh, 2012). The test yielded an agreement score of 0.76, indicating a high level of agreement between the validators (Viera & Garrett, 2005). Following this, content validity was assessed using the Content Validity Index (CVI) based on Aiken's Coefficient Value (Aiken, 1980). The validity test results showed that all five items for both the pre-test and post-test had a CVI > 0.80, signifying high validity (Almanasreh et al., 2019). Subsequently, the reliability of the test instrument was assessed using Cronbach's Alpha coefficient, yielding a value of $\alpha = 0.82$. According to the criteria established by Taber (2018), this value indicates a good and strong level of reliability; thus, the instrument was confirmed to be reliable.

Data Collection

According to the research design (see Figure 1), data collection was conducted in three stages: pre-test, treatment, and post-test. In the initial stage, the researchers administered the pre-test to both the experimental and control classes. This pre-test aimed to measure students' initial conceptual understanding ability in both classes, serving as a baseline to determine initial equivalence.

Subsequently, the treatment phase was conducted through instruction on the topic of curved surface solids, with an equal number of sessions and time allocation for both classes. Prior to implementation, the researcher provided specific instructions to the teacher regarding the use of the interactive e-module in the experimental class. During the learning process, the researcher acted as an observer and provided technical assistance if students encountered difficulties accessing the e-module, without directly intervening in the delivery of material or conceptual guidance.

Furthermore, instruction in the experimental class utilized the interactive constructivist-based e-module to facilitate the guided discovery learning process. Organized into collaborative groups, students were directed to explore contextual problems and construct conceptual understanding by manipulating visual representations and three-dimensional models directly within the e-module. They were also encouraged to engage in group discussions to articulate their findings and negotiate mathematical meanings derived from their digital exploration.

Conversely, the control class received instruction based on the same approach; however, it employed conventional textbooks and available physical manipulatives instead of the interactive e-module. Similarly, working in collaborative groups, students in this class were actively guided to explore the concepts, identify properties of curved solids, and engage in discussions based on the material presented in the textbook. The teacher played a consistent role as a facilitator in both classes, guiding the inquiry process without directly providing the answers. Thus, the primary distinction between the two classes lay solely in the instructional media utilized: the interactive e-module in the experimental class and conventional textbooks in the control class.

Upon completion of the treatment phase, a post-test was administered to both classes to measure the mathematical conceptual understanding capabilities of students in the experimental and control groups. The results of this post-test served as the basis for comparing the students' mathematical conceptual understanding achievement and determining the effect of the treatment administered.

Data Analysis

Data analysis employed inferential statistics to test the difference in mathematical conceptual understanding ability between the experimental and control classes. An independent samples t-test was used if the data met the assumptions of normality and homogeneity. Conversely, if the data failed to meet these assumptions, the non-parametric Mann-Whitney U test was employed as an alternative (Nikitina & Chernukha, 2022). For the Mann–Whitney U test, effect size was calculated using the r statistic ($r = Z/\sqrt{N}$). Effect size interpretation followed Cohen's guidelines, where r values below ±0.10 indicate a weak effect, below ±0.30 a modest effect, below ±0.50 a moderate effect, below ±0.80 a strong effect, and values equal to or exceeding ±0.80 indicate a very strong effect (Cohen et al., 2000). Additionally, descriptive statistics were used to determine which class demonstrated superior conceptual understanding ability. The class with the highest mean score or best median was considered to possess better conceptual understanding ability. All data analysis procedures were performed using SPSS 16 software.

RESULTS & DISCUSSION

Result

Pre-test Data Analysis

The pre-test scores were used to assess the suitability of the research sample selection prior to treatment administration. This suitability was based on the initial equivalence of ability between the experimental and control classes. An independent samples t-test was planned for this purpose. However, prior to conducting this test, normality and homogeneity tests were performed. Table 2 presents the results of the pre-test data normality and homogeneity tests.

Table 2. Results of the Normality and Homogeneity Tests on Pre-test Scores

		Class	Significance
Normality Test	Shapiro-Wilk	Experiment	0.328
		Control	0.031
Homogenity Test	Levene's Test	Experiment*Control	0.017

Based on Table 2, the pre-test normality test results showed a significance value of 0.328 > α = 0.05 for the experimental class and 0.031 < α = 0.05 for the control class. This indicates that the pre-test data for the control class were not normally distributed. Consequently, the assumption of normality was not met. Meanwhile, the pre-test homogeneity test yielded a significance value of 0.017 < 0.05, indicating that the two classes did not have equal variances (i.e., were not homogeneous). Therefore, the assumption of homogeneity was also not met.

Given that the assumption of normality was violated in the control group and the assumption of homogeneity of variance was also not met, the use of the independent samples t-test required careful consideration. Although the t-test is generally robust against moderate violations of normality—particularly when sample sizes across groups are relatively comparable—the combination of a non-normal data distribution in one group and heterogeneous variances necessitated the adoption of a more conservative analytical approach. Consequently, the non-parametric Mann–Whitney U test was employed to compare pre-test scores between the groups.

Test Statistics[a]

	Score
Mann-Whitney U	371.000
Wilcoxon W	836.000
Z	-1.537
Asymp. Sig. (2-tailed)	.124

Figure 2. Results of the Mann–Whitney U Test on Pre-test Scores

Based on the Mann-Whitney U test results shown in Figure 2, a significance value of 0.124 > α = 0.05 was obtained. This signifies no significant difference in the mean pre-test scores between the experimental and control classes. Therefore, it can be concluded that both classes possessed equivalent initial mathematical conceptual understanding ability and were suitable as the research sample.

Post-test Data Analysis

Following the pre-test, the researchers administered a post-test to students after they completed learning the curved solids topic. In the experimental class, learning was facilitated using the interactive constructivist philosophy-based e-module. This post-test aimed to determine whether a difference existed in mathematical conceptual understanding ability between the experimental and control classes after the treatment. An independent samples t-test was planned. However, normality and homogeneity tests for the post-test data were conducted first. Table 3 displays the results of these post-test data normality and homogeneity tests.

Table 3. Results of the Normality and Homogeneity Tests on Post-test Scores

		Class	Significance
Normality Test	Shapiro-Wilk	Experiment	0.884
		Control	0.002
Homogenity Test	Levene's Test	Experiment*Control	0.447

Based on Table 3, the post-test normality test results showed a significance value of 0.884 > α = 0.05 for the experimental class and 0.002 < α = 0.05 for the control class. This indicates that the post-test data for the control class were not normally distributed. Thus, the normality assumption was not satisfied. Meanwhile, the post-test homogeneity test yielded a significance value of 0.447 > α = 0.05, indicating that the two classes had equal variances (i.e., were homogeneous). Therefore, the homogeneity assumption was satisfied.

Although the assumption of homogeneity of variance was satisfied, the normality test results indicated that the post-test data for the control group were not normally distributed. Under these conditions, the employment of the independent samples t-test warranted careful deliberation. While the t-test is generally robust against violations of normality, the presence of a non-normal distribution in one of the groups led to the selection of a more conservative analytical approach. Thus, the comparison of post-test scores between the experimental and control groups was analyzed using the non-parametric Mann–Whitney U test. The hypothesis tested by the Mann-Whitney U test was as follows.

H_0: There is no significant difference in the post-test scores of students' conceptual understanding between the experimental and control classes.

H_a: There is a significant difference in the post-test scores of students' conceptual understanding between the experimental and control classes.

Test Statistics[a]

	Score1
Mann-Whitney U	49.000
Wilcoxon W	577.000
Z	-6.078
Asymp. Sig. (2-tailed)	.000

Figure 3. Results of the Mann–Whitney U Test on Post-test Scores

Based on Figure 3, the Mann-Whitney U test yielded a significance value of $0.000 < \alpha = 0.05$. This means H_0 was rejected, indicating a significant difference in the post-test scores of students' conceptual understanding ability between the experimental and control classes. In addition to statistical significance, the magnitude of the treatment effect was assessed using effect size. The effect size was calculated using the statistic r, yielding a value of $r = 0.77$. According to Cohen's criteria, this value falls into the 'strong effect' category, indicating that the observed difference was not only statistically significant but also practically meaningful within the context of mathematics learning.

To determine which group demonstrated better conceptual understanding, descriptive statistics presented in Figure 4 were used. It can be observed that the median for the experimental class (median=75) was higher than that of the control class (median=55.5). This signifies that students in the experimental class, who learned curved solids using the interactive constructivist philosophy-based e-module, possessed better mathematical conceptual understanding ability than students in the control class. Therefore, it can be concluded that the implementation of the interactive constructivist philosophy-based e-module was effective in enhancing students' mathematical conceptual understanding ability, specifically on the topic of curved solids.

Statistics

		Experiment	Control
N	Valid	30	32
	Missing	32	30
Mean		75.4667	54.5000
Median		75.0000	55.5000
Std. Deviation		10.13609	8.98386
Variance		102.740	80.710
Sum		2264.00	1744.00

Figure 4. Descriptive Statistics of Post-test Score

To further elucidate the comparison of students' conceptual understanding achievements before and after the intervention, Figure 5 presents a comparison of the pre-test and post-test median scores for both the experimental and control groups. At the pre-test stage, both groups exhibited relatively comparable median scores (Control = 48; Experimental = 45), indicating that the two groups possessed equivalent initial mathematical conceptual understanding abilities prior to the intervention. However, at the post-test stage, a distinct difference emerged between the two groups. The experimental group demonstrated a higher median score (median = 75) compared to the control group (median = 55.5). This discrepancy suggests that students who learned using the interactive constructivist-based e-module achieved a superior level of mathematical conceptual understanding compared to those who received conventional instruction.

Furthermore, a comparison of pre-test and post-test scores within each group revealed that the enhancement of conceptual understanding was more pronounced in the experimental group than in the control group. This finding reinforces the statistical test results, demonstrating that the use of the interactive constructivist-based e-module had a significant impact on improving students' mathematical conceptual understanding of geometry of curved surface solids.

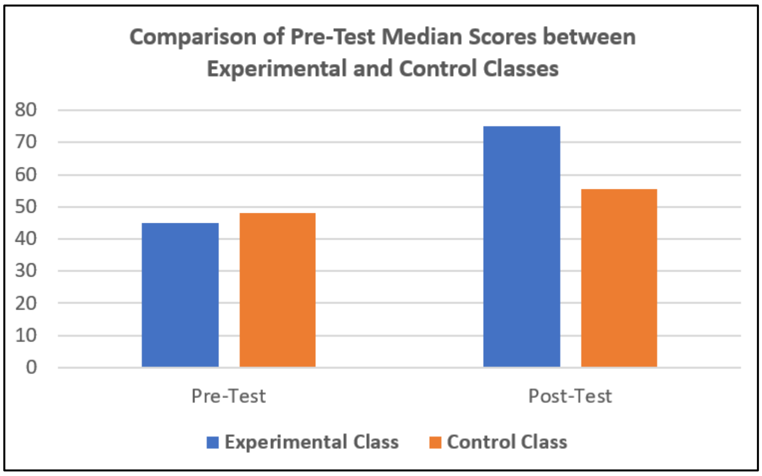

Figure 5. Median Score of Students' Conceptual Understanding in the Experimental and Control Classes

Discussion

The results of this study indicate that students who learned using the interactive constructivist-based e-module possessed significantly better mathematical conceptual understanding of geometry of curved surface solids compared to students who underwent conventional instruction. This finding corroborates the view of Stahl (2021) that instructional designs integrating contextual experiences, dynamic visual exploration, and digital scaffolding align with the way students construct spatial geometry concepts. Theoretically, this improvement in conceptual understanding can be elucidated through the frameworks of Piaget's (1972) and Bruner's (1961) constructivism. From Piaget's (1972) perspective, knowledge construction occurs through the mechanisms of assimilation and accommodation, whereas Bruner (1961) posits that conceptual understanding is formed optimally when students actively discover mathematical principles through structured exploration and the use of progressively developing representations. These two frameworks were operationalized within the e-module through the design of learning activity sequences and interactive features, including GeoGebra-assisted spatial visualization, which guided students from concrete experiences to visual representations and finally to formal mathematical understanding.

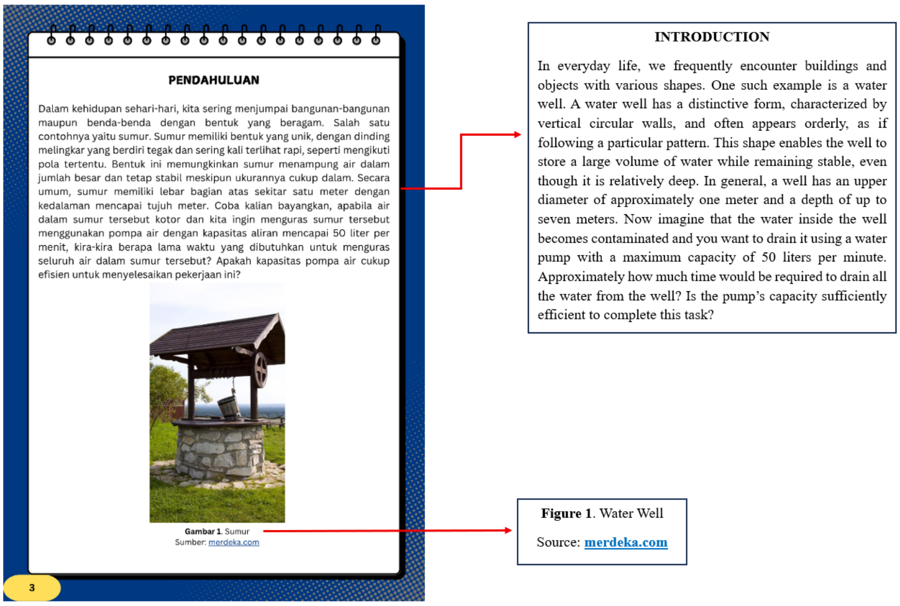

Figure 6. Introduction Section of E-Module

The core activities within the e-module commenced with the presentation of contextual problems close to students' daily lives, such as representing a well as a cylinder, which served to activate students' prior knowledge as a form of initial assimilation of new experiences (see Figure 6). Subsequently, students were directed to represent contextual objects into formal geometric forms, identify the elements of the solids, and derive formulas for surface area and volume (see Figure 7). At this stage, the integration of GeoGebra within the e-module (see Figure 8) enabled students to perform visual and manipulative exploration of three-dimensional models and geometric nets, thereby fostering accommodation—the process of adjusting and restructuring initial understanding into more formal and integrated mathematical concepts (Posumah et al., 2024; Sieng & Thai, 2024). Furthermore, the presence of step-by-step guidance, immediate feedback, and dynamic visualizations within the e-module served as a form of digital scaffolding, as emphasized in Bruner's (1961) guided discovery learning theory, which functioned to systematically direct and support the students' process of discovery.

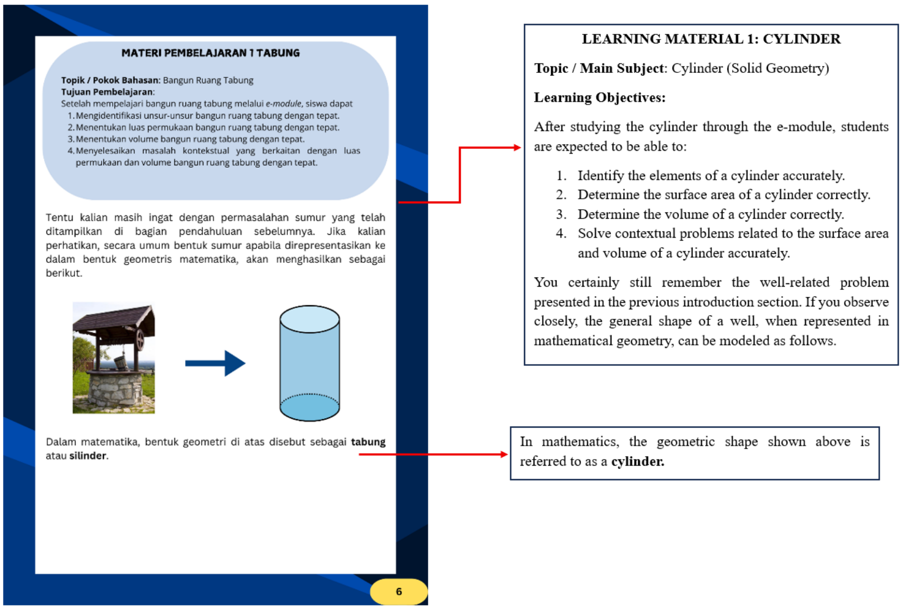

Figure 7. Representation of Concrete Object into Geometric Shape

Moreover, the reinforcement of students' conceptual understanding of curved surface solids in this study was not solely influenced by the sequence of learning activities and digital scaffolding, but was also mediated by the development of visual-spatial abilities facilitated through the design of the constructivist-based e-module. Inherently, understanding spatial geometry concepts demands students' ability to visualize three-dimensional objects, manipulate spatial representations, and comprehend the relationships between geometric shapes, nets, and mathematical formulas (Choo et al., 2020; Kmetová & Lehocká, 2021). In this context, GeoGebra did not function as a standalone technological tool, but rather as an integrated cognitive tool to support the process of concept construction. Through interactive exploration of three-dimensional models and geometric nets (see Figure 8), students did not merely observe objects statically, but also rotated, disassembled, and visually reconstructed geometric representations. Such activities strengthened visual-spatial reasoning as a mediating cognitive mechanism, bridging visual experiences with the formation of more formal, structured, and meaningful geometric concepts (Liu et al., 2021).

Furthermore, the disparity in conceptual understanding achievement between the experimental and control groups can be elucidated through the lens of scaffolding and the Zone of Proximal Development (ZPD), as proposed by Vygotsky (1978). In the experimental group, the interactive e-module provided supplementary technology-based scaffolding through structured guidance, dynamic visualizations, and immediate feedback. These features assisted students in completing tasks that initially lay beyond their independent capabilities. Such support enabled students to construct understanding progressively, in alignment with the principles of ZPD (Reinhold et al., 2020; Xi & Lantolf, 2021). Conversely, although instruction in the control group also implemented guided discovery with the teacher acting as a facilitator, the available scaffolding was predominantly verbal and static, relying on textbooks. The lack of interactive visualization in this setting rendered the exploration and reconstruction of concepts regarding curved surface solids suboptimal (Martin et al., 2019). It is this divergence in scaffolding characteristics that likely contributed to the observed difference in the enhancement of conceptual understanding between the two groups (Alanazi et al., 2024).

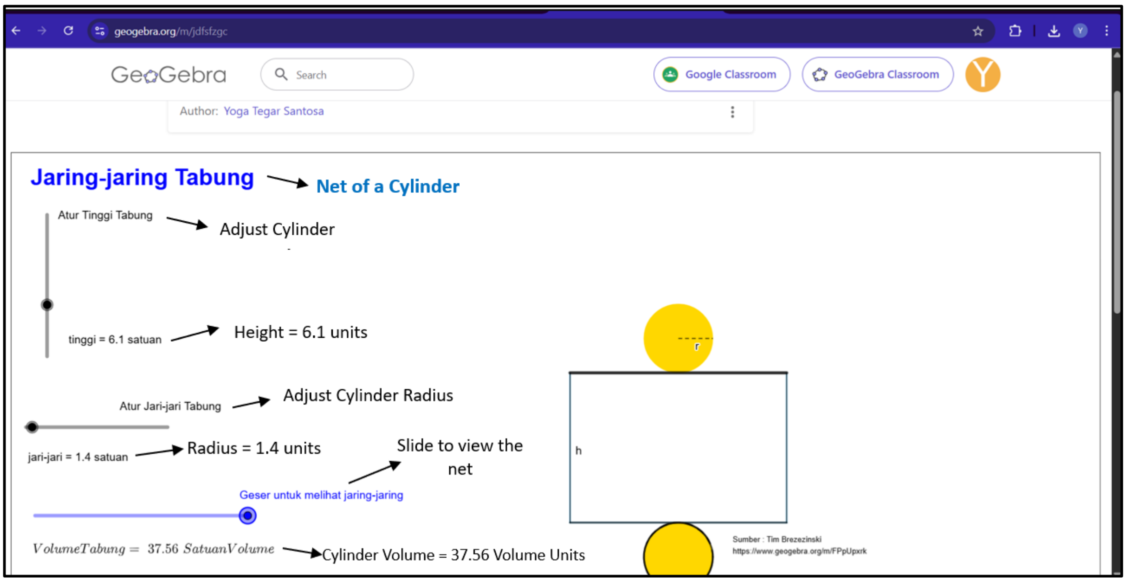

Figure 8. Visualizing Curved Solids with GeoGebra

Moreover, the findings of this study are consistent with a body of prior research demonstrating that e-modules grounded in a constructivist approach are effective in enhancing students' conceptual understanding. For instance, Maglinte & Coronica (2023) reported that e-modules based on constructivist philosophy were capable of improving students' conceptual understanding through active engagement in the learning process, albeit within different contexts and subject areas. Similarly, Istuningsih et al. (2018) found that e-modules developed upon specific pedagogical foundations yielded a positive impact on conceptual understanding and learning outcomes. Additionally, Zulfahrin et al. (2019) indicated that Problem-Based Learning (PBL)-based e-modules could enhance conceptual understanding by presenting contextual problems as the starting point of instruction. These findings reinforce the results of the present study by demonstrating that the effectiveness of interactive e-modules does not reside solely in their digital nature, but rather in the integrated constructivist instructional design that consciously facilitates the knowledge construction process through contextual experiences, exploration, and reflection.

Theoretical Contribution and Limitations

Theoretically, this study contributes to the scholarship of mathematics education by indicating that the improvement of students' conceptual understanding of curved surface solids is influenced not only by the cognitive constructivist approach as a philosophical foundation, but also by the integration of dynamic visual tools that function as cognitive scaffolding within the framework of guided discovery learning. In this context, the GeoGebra integrated into the e-module does not operate as a distinct factor, but rather serves as a mediating tool that operationalizes Piaget's principles of cognitive constructivism and Bruner's theory of guided discovery through spatial visualization, manipulative exploration, and the provision of graduated support guiding the students' process of concept discovery.

Notwithstanding these contributions, these findings must be interpreted with caution due to the study's limitations. The research involved a sample restricted to a single school and a specific geometry topic, thereby limiting the generalizability of the findings. Furthermore, there is a possibility of a novelty effect, wherein the observed improvement in student performance may be partially attributed to the novelty of utilizing interactive e-modules and digital technology. Consequently, future research is recommended to involve more diverse school contexts, longer intervention durations, and research designs that allow for a more distinct separation between pedagogical effects and technological effects.

CONCLUSION

This study aimed to examine the effect of using an interactive constructivist philosophy-based e-module on junior high school students' mathematical conceptual understanding of geometry of curved solids. The results of this study demonstrate that students who utilized the constructivist-based interactive e-module exhibited significantly higher mathematical conceptual understanding compared to those who did not employ the e-module. This finding is corroborated by the results of the Mann–Whitney U test (Sig. $p < \alpha = 0.05$) as well as the disparity in post-test median scores between the experimental group (median = 75) and the control group (median = 55.5). Beyond statistical significance, the distinction in conceptual understanding achievement was evidenced by a large effect size ($r = 0.77$), indicating a practically meaningful difference between the two groups. Nevertheless, these findings warrant cautious interpretation given the study's quasi-experimental design and the lack of complete equivalence between the groups. The enhancement of students' conceptual understanding in the experimental group cannot be causally attributed solely to the use of the e-module, as other factors—such as the novelty effect or increased motivation resulting from engagement with interactive digital media—may have played a role. Consequently, this study provides empirical evidence regarding the potential of constructivist-based interactive e-modules as an alternative learning resource in mathematics. Simultaneously, it underscores the necessity for future research involving longer intervention durations, broader sample coverage, and more rigorous research designs to strengthen causal inferences and investigate long-term impacts on students' higher-order thinking skills.

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