

THE DEVELOPMENT OF GEOGEBRA AUGMENTED REALITY-ASSISTED CONTEXTUAL TEACHING MATERIAL TO IMPROVE CREATIVE THINKING SKILLS

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ABSTRACT

The rapid development of digital technology has opened up opportunities to integrate innovative media into mathematics learning, particularly geometry, where students often struggle with spatial visualization and creative problem-solving. Conventional learning materials are often insufficient to stimulate student engagement and creative thinking. This study aims to develop contextual-based teaching materials assisted by GeoGebra Augmented Reality (AR) to enhance students' mathematical creative thinking skills. This study uses a Research and Development (R&D) approach with the ADDIE model. In the analysis phase, students' difficulties in understanding spatial figures and their low creative thinking performance were identified. The design phase produced a contextual framework supported by AR visualizations that aligned with the learning objectives. During the development phase, GeoGebra AR was integrated into the materials to create interactive and easily manipulated representations of polyhedra. The implementation phase involved limited and large-scale trials with Grade VIII students of SMP Pasundan 1 Cimahi. In the evaluation phase, expert validation and student response data were analyzed to determine the validity, practicality, and effectiveness of the developed product. The findings indicate that this teaching material is highly valid, as demonstrated by evaluations from material experts and ICT experts. Student responses in both trial phases also demonstrated a high level of practicality and positive acceptance. Furthermore, this teaching material proved highly effective in improving students' mathematical creative thinking skills, achieving an effectiveness rate of 96%. It can be concluded that the contextual teaching material assisted by GeoGebra AR developed in this study can support teachers in creating innovative, engaging, and conceptually meaningful learning experiences for students.

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INTRODUCTION

Creative thinking ability is a crucial cognitive competency that students must develop to generate ideas, explore alternative solutions, and construct meaningful mathematical understanding. In mathematics education, creative thinking plays an essential role because students are required not only to apply formulas but also to reason flexibly, devise strategies,

and reinterpret problems innovatively. Torrance (1974) describes creative thinking as consisting of four indicators: fluency (ability to generate many ideas), flexibility (ability to propose various strategies), originality (ability to produce unique ideas), and elaboration (ability to refine and detail ideas). These indicators form the foundation for students to engage in higher-level mathematical reasoning and to respond effectively to increasingly complex real-world challenges. Despite its importance, global and national studies indicate that students' mathematical creative thinking remains low, especially in geometry. International data show that learners often struggle with tasks requiring spatial visualization, idea generation, and conceptual flexibility (Jones et al., 2020).

In Indonesia, similar patterns emerge; students find it difficult to visualize three-dimensional objects, create alternative solutions, and elaborate mathematical ideas, particularly in flat-sided solid figure topics (Putra & Nuryadi, 2022). These issues stem largely from teacher-centered instructional approaches, minimal opportunities for exploration, and the absence of interactive media capable of supporting creative mathematical reasoning (Mulyana et al., 2023). A needs analysis at SMP Pasundan 1 further reveals that students experience difficulty in imagining geometric structures, generating creative solutions, and constructing detailed reasoning skills directly aligned with Torrance's indicators of creative thinking. Teaching materials serve as essential tools to develop students' creative thinking abilities. High-quality instructional materials not only deliver information but also promote exploration, questioning, and independent discovery.

Research shows that teaching materials designed with open-ended activities can significantly enhance fluency, flexibility, originality, and elaboration in students' mathematical thinking (Rahmawati & Kartono, 2021). Contextual teaching materials, in particular, connect mathematics to real-life situations, enabling meaningful learning and stimulating higher-order thinking skills (Lestari, 2018; Ministry of Education, 2014). Amelia and Ningsih (2020) found that exploration-based and discussion-oriented teaching materials increase students' ability to articulate and elaborate mathematical ideas. These findings affirm that teaching materials are central to shaping students' creative cognitive development, not merely supplementary resources. Alongside teaching innovations, developments in digital technology have opened vast opportunities to cultivate creative thinking. Sari (2024) highlights that interactive digital environments create dynamic and personalized learning experiences that significantly boost students' cognitive and creative engagement.

GeoGebra a dynamic mathematics software supports creativity by enabling students to manipulate objects, explore patterns, test hypotheses, and generate new representations. With the integration of Augmented Reality (AR), GeoGebra advances these possibilities further by projecting virtual three-dimensional objects into real-world environments, allowing learners to observe shapes from different angles, enlarge or rotate them, and interact with spatial structures in an intuitive and immersive manner. The role of AR in enhancing creative thinking has been strongly supported by research. Suh and Prophet (2018) state that AR encourages curiosity and idea generation through hands-on, immersive interaction with virtual objects. Sirakaya and Cakmak (2018) found that AR significantly improves students' ability to visualize geometric figures from multiple perspectives, thereby enhancing fluency and elaboration in mathematical problem solving. A systematic review by Bacca et al. (2014) demonstrated that AR promotes exploration, increases motivation, and enhances conceptual creativity across educational fields. Similarly, Diva et al. (2023) report that GeoGebra AR encourages exploratory learning behaviors that strengthen flexibility and originality in students' mathematical reasoning. Yerushalmy and Shternberg (2020) further confirm that dynamic geometry environments like GeoGebra support reasoning and creativity by offering interactive representations and opportunities for students to test and refine their ideas. Integrating contextual teaching materials

with augmented reality thus provides a powerful learning framework for enhancing mathematical creative thinking.

Contextual tasks facilitate meaningful engagement, problem formulation, and the application of mathematics to real-life situations, while AR allows learners to visualize and manipulate three-dimensional structures directly. This combination stimulates all four indicators of creative thinking: students can generate multiple ideas (fluency), explore various strategies (flexibility), propose unique solutions (originality), and refine their reasoning (elaboration). Moreover, this approach accommodates diverse learning styles visual, kinesthetic, and exploratory making abstract mathematical concepts more concrete and engaging. Given the challenges students face in developing creative thinking abilities and the strong potential of AR-based contextual teaching materials, this study aims to develop instructional materials that are valid, practical, and effective in improving students' mathematical creative thinking abilities in learning flat-sided geometric solids. Specifically, this research seeks to produce innovative teaching materials using GeoGebra AR that promote idea generation, encourage flexible reasoning, stimulate originality, and support elaborative thinking. Furthermore, this study is expected to contribute to the advancement of technology-integrated mathematics education that aligns with the needs of 21st-century learning and supports the development of creative, critical, and digitally literate students.

METHOD

This research used a Research and Development (R&D) approach with the ADDIE development model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The subjects were eighth-grade students at SMP Pasundan 1 Cimahi, while the object of the study was teaching materials on flat-sided solids developed by integrating a contextual approach and interactive GeoGebra Augmented Reality (AR) media.

The analysis phase was conducted to identify student and teacher needs through interviews, observations, and literature reviews. This resulted in information regarding student difficulties with flat-sided solids and the need for interactive learning media. The design phase included the creation of a prototype teaching material that included learning objectives, materials, student activities, and GeoGebra AR integration relevant to real-life contexts.

During the development phase, the prototype teaching material was validated by material experts and media experts to assess the appropriateness of the content, language, presentation, and graphics. The validation results were analyzed and used to make revisions to ensure the product was suitable for pilot testing. The implementation phase involved applying the teaching materials to a pilot class, followed by pretests and posttests to measure mathematical creative thinking skills and a questionnaire to gauge student learning interest.

The evaluation phase included assessing the effectiveness of the teaching materials based on test and questionnaire results, as well as input from teachers and students. Data analysis was conducted using descriptive qualitative methods to describe the development process and expert validation results, and quantitative methods using the N-gain test to assess student performance improvement, normality and homogeneity tests to meet statistical assumptions, and a t-test to examine differences in results before and after the use of the teaching materials.

RESULTS AND DISCUSSION

Results

The results of this research produced teaching materials on flat-sided geometric shapes using a contextual approach assisted by GeoGebra. The results of the research and development conducted were based on the following research problems:

1. Development of Teaching Materials Using Geogebra AR on Flat-Sided Space Structures

The development of teaching materials was carried out on the material of flat-sided solid shapes using a contextual approach assisted by Geogebra. The development model used was the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), the following is an explanation of the development of teaching materials using the ADDIE model.

a. Analysis Level

Prior to the analysis phase, a research team was formed consisting of students as researchers and lecturers as supervisors. The research began with collecting information on students' cognitive abilities and learning interests, which showed both were still low, necessitating a review of the teaching materials used. Analysis was conducted through interviews with mathematics teachers at SMP Pasundan 1 Cimahi, who revealed that students still had difficulty understanding the material on flat-sided solid shapes, mainly due to limited media and learning approaches used. Teachers generally used textbooks and a scientific approach, rarely used a contextual approach assisted by GeoGebra, and faced low student activeness, indifference towards assignments, and difficulty understanding concepts related to previous material. Although exercises and tutorials helped some students, understanding was not uniform. Based on these findings, the researchers identified the need to develop teaching materials based on interactive GeoGebra technology with a contextual approach to improve students' cognitive abilities and learning interests.

b. Design Stage (Planning)

At this stage, the researcher began designing teaching materials for the Flat-Sided Solid Geometry topic using the GeoGebra application. This design not only focuses on the content of the material, but also pays attention to the visual appearance to make it more attractive and the images used are presented clearly and proportionally, equipped with a combination of colors that are not monotonous to avoid boredom with the aim of making learning more interesting, interactive, and easy to understand for students. The following is an overview of the teaching materials that will be used.

a) Teaching Materials

The design of the teaching materials here, which is centered on two teaching materials, namely worksheets (LKS) and teaching materials, is the researcher's first step in creating interesting and interactive teaching materials. These teaching materials do not simply contain practice questions, but are designed to encourage students to think critically, explore, and actively understand the concept of geometric shapes. Using a contextual approach and the help of the GeoGebra application, learning is made more realistic, easy to understand, and fun. The materials presented include cubes, blocks, prisms, and pyramids, with activities involving observation, discussion, and experimentation. Students are invited to relate the material to real objects around them, such as cardboard or tents, so that the concepts of surface area and volume are discovered independently, not just memorized. GeoGebra helps visualize geometric shapes in 3D format, allowing students to rotate, zoom in, and observe each part in detail, so that understanding becomes deeper than just looking at two-dimensional images in books.

b) Cover

The cover of the teaching material is developed to make the teaching material seem attractive with an attractive color choice, an attractive font to open the enthusiasm for students. The cover contains information on each meeting such as sub-chapters of the discussion that will be discussed at each meeting, group identity, KI and KD as well as learning objectives and how to do it. The cover is also provided with space for students to write the name of the class group and the names of each member.

c) Contents Section

The content section of this teaching material is designed to provide an active, contextual learning experience and encourage student creativity through contextual approach steps, such as constructivism, inquiry, questioning, learning community, modeling, reflection, and authentic assessment. Students are invited to observe real objects in the form of cubes, explore their elements with teaching aids and GeoGebra, then formulate questions and discuss in groups to compare nets, discover the concept of surface area and volume using GeoGebra. The teacher gives examples of using GeoGebra to calculate area and volume, which students then apply to real situations. The activity ends with reflection and authentic assessment through the creation of cube nets and calculating their dimensions. With this flow, this teaching material becomes a medium for exploration and creative thinking that makes learning more lively and meaningful.

d) Conclusion

In the closing section of the Teaching Materials, a column is provided for students to write a summary of the material they obtained in the learning process with their group members. This section is also equipped with a formative test. The following is a brief display of the closing section.

c. Development Stage

In the development stage of the teaching materials, the worksheets (LKS) and learning videos used a contextual approach assisted by GeoGebra. Validation and practicality tests were then conducted. After validation, the researchers made improvements to the developed teaching materials. These improvements were based on the validation and evaluation results from implementation activities and the results of scale assessments in limited and extensive tests. The following are the steps the researchers took in the development stage: Validitas

a) Material Expert Validity Test

Expert validation was carried out in two stages, namely Limited trial validation conducted before the limited test and Extensive trial validation conducted after improvements or in other words before the extensive test was conducted. Initial validation was carried out by one of the lecturers as supervisor 2 and 6 teachers (2 mathematics teachers, Indonesian language teachers and ICT teachers) and 2 principals of SMP Pasundan 1 Cimahi and SMP Pasundan 3 Cimahi. Material expert validation was carried out with the aim of finding out what aspects had not yet been achieved in the teaching materials that the researcher had designed. The following are the results of the limited and final trial validation by material experts:

Table 1. Recapitulation of Expert Validation Assessment of Limited Trial Material and Extensive Trial Based on Observed Aspects

Observed Aspects	Item Number	Presentation	
		Limited Trial	Wide-Range Trial
Material Suitability	1,2,3,4	88,40%	94,38%
Suitability of Student Abilities	5,6	82,00%	91,25%
Suitability of Method/Approach	7,8,9,10, 11	87,00%	96,00%
Suitability of Geogebra Learning Media	12,13,14	79,21%	97,17%
Compliance of LKS with construction requirements	15,16,17,18,19,20,21	82,00%	94,29%
Technical Conformity Aspects	22,23,24, 25,26	84,50%	93,50%
Average Percentage		83,85%	94,43%
Validation Test Criteria		Valid	Very Valid

The results of the limited trial showed an average validation percentage of 83.85% with the Valid criteria, so the product can be used with minor revisions. Improvements were made to the writing, grammar, and display aspects of GeoGebra. After revisions, a comprehensive trial was conducted, resulting in an average percentage of 94.43% with the Very Valid criteria, indicating the product is suitable for use without further improvements.

b) Validity of ICT Experts

ICT validation was conducted in two stages, namely limited trial validation and extensive testing. Validation was conducted by three ICT experts, namely 2 ICT subject teachers and native ICT staff at UNJANI. Assessment in the ICT expert validation prioritized the Geogebra software providing an assessment in terms of technology and the appearance created. The instrument used was a feasibility and validity test scale assessed by ICT experts in terms of Geogebra and teaching materials.

Table 2. Recapitulation of ICT Expert Validation Assessment Limited Trial and Extensive Trial Based on Observed Aspects

Observed Aspects	Item Number	Presentation	
		Limited Trial	Wide-Range Trial
<i>Software Geogebra</i>			
Visual Display	1,5	84,50%	90,40%
Educative	2,3,4,5,6,7,8	90,25%	97,25%
Teaching Materials			
Visual Display	9,10, 12, 14	85,50%	92,00%

Accessibility and Education	11,13,15	80,75%	90,00%
Average Percentage		85,25%	92,41%
Validation Test Criteria		Valid	Very Valid

Based on Table 2, which was provided by the ICT validator in the limited trial, an average percentage of 85.25% was obtained, with the validation result criteria being Valid with slight revisions to small elements such as color and font size. After the researcher made revisions, a broad trial was conducted with an average research result of 92.41% with the criteria of Very Valid.

c) Practicality Tes

This practicality test was conducted to measure the practicality of the teaching materials by observing student responses to the materials developed by the authors. This included both limited and broader trials. The following is a summary of the practicality test results from the limited trials.

Table 3. Recapitulation of ICT Expert Validation Assessment Limited Trial and Extensive Trial Based on Observed Aspects

No	Respondent Material Teaching	Limited Trial		Wider Trial	
		Average	Criteria	Average	Criteria
1	Meeting 1	85,08	Practical	94,38%	Very Practical
2	Meeting 2	83,36	Practical	95,25%	Very Practical
3	Meeting 3	84,36	Practical	96,00%	Very Practical
4	Meeting 4	84,08	Practical	97,17%	Very Practical
5	Meeting 5	83,03	Practical	94,29%	Very Practical
6	Meeting 6	85,36	Practical	93,50%	Very Practical
Average percentage		84,21%		95,10%,	
Practicality Test		Practical		Very Practical	

Based on Table 3 and the results of the assessment that has been given to 10 students, the average percentage of the practicality test was 84.21%, which means that the product is Practical with a few revisions. After the researcher made the revision, the researcher conducted a wide trial to measure the level of practicality of the new teaching materials that have been revised by giving a trial to 28 students. The following are the results of the practicality test on the Wide Trial of Teaching Materials. then the average percentage of practicality in the wide trial was 95.10%, which means that the product is Very Practical without any revisions. This shows that the teaching materials that have been developed are ready to be used in the implementation of learning.

d. Implementation Stage

After the teaching materials were declared valid, they were tested in learning activities. The trials were conducted to determine the feasibility and attractiveness of the teaching materials, using a contextual approach and GeoGebra-assisted learning media, which

were used to improve students' creative mathematical thinking skills and learning interest.

e. Evaluation Stage

The design stage evaluation showed that GeoGebra-assisted teaching materials needed to be packaged simply for student ease of use. A questionnaire was distributed to media experts, material experts, and students to assess the feasibility and attractiveness of the teaching materials. Based on these results, the research proceeded to the development stage by measuring feasibility through an effectiveness test. The effectiveness test was conducted after six learning sessions using the teaching materials, by providing five questions on mathematical creative thinking skills. Effectiveness was assessed from the results of the posttest, which students achieved or exceeded the Minimum Competency (KKM) (75).

Table 4. Recapitulation of Teaching Material Effectiveness Test

Number of Students Reaching the Minimum Competency (KKM)	Effectiveness Percentage	Uji Keefektifan
28	96%	Effectiveness Test

As can be seen from Table 4, the percentage of effectiveness of the teaching materials as seen from the results of students' mathematical creative thinking ability scores obtained a percentage of 96%, which is included in the Very Effective category. Based on this, it can be concluded that the teaching materials that have been developed and tested are stated to be Very Appropriate and Very effective for use in implementing learning.

2. Scenario and Implementation of Flat-Sided Space Structure Material Teaching Materials Using Geogebra AR

The study involved two classes, namely class 9A as an experiment that used contextual approach-based teaching materials with the help of GeoGebra, and class 9C as a control that used conventional learning. Before teaching, the teacher prepared a learning scenario in the form of a Lesson Implementation Plan (RPP) to regulate time allocation, classroom management, and achievement of learning objectives. For the material of flat-sided solid shapes, the learning scenario was arranged according to the number of materials, allocation of Lesson Hours (JP), and referring to the 2013 Curriculum, including Core Competencies (KI), Basic Competencies (KD), and Competency Achievement Indicators

a. Scenario and Implementation of Experimental Class Learning in Product Testing

Researchers conducted an experiment by testing GeoGebra-assisted teaching materials based on a contextual approach to improve students' creative thinking skills and learning interests. In the first meeting, learning began with a transition that built teacher-student interaction, the formation of heterogeneous learning groups, and an initial orientation in the form of greetings, prayers, attendance checks, and physical and psychological preparation of students. The teacher then conducted an apperception by introducing the material on flat-sided solid shapes and learning resources, followed by motivation that emphasized the benefits of studying the material. Next, learning linked the material to everyday life through worksheets designed according to scenarios, with the application of contextual syntax in a structured manner.

1) Constructivism

At this stage, the teacher provides stimulus and presents contextual problems that must be observed by students, namely pictures on the worksheet and by remembering objects in everyday life, then writing them on the worksheet section that has been provided with the knowledge they build themselves based on what they already know. In the teaching material, the teacher provides stimulus and explains the concept of the material simply, this is done so that at this constructivism stage, students can construct knowledge based on what they already know and can construct it to new problems. Then students can also construct students' understanding of the cube space by scanning the Augmented Reality (AR) QR-Code and observing it in the middle of their respective group tables.

2) Inquiry

In the inquiry stage, the teacher asks students to observe the Geogebra AR that has been made and is asked to find the elements of the cube and then many of its elements and pour them into the LKS and at this stage also invites students to observe the Geogebra application about cube nets and the Geogebra application that contains the concept of cube volume. This stage is the core stage in Contextual because basically students are expected to acquire knowledge and skills by themselves, not the result of memorization, but students discover their own knowledge by discussing with their group.

3) Questioning

The teacher opens a discussion space for asking questions, this stage is the main stage in contextual learning, because the teacher can encourage, assess and guide students to build their own thoughts in a question. It takes a stimulus to make students ask questions, some students are already active in various questions but to make students feel confident asking questions requires encouragement that makes students feel the need for additional information by asking questions besides in the learning process students are stimulated to ask but in the LKS students are instructed to make questions. In this stage after students explore their own knowledge, then students ask about what they think they have not understood, a question that makes the process of critical thinking of students after carrying out the inquiry stage or building their own knowledge. Student activeness in the questioning process is very visible, measuring skills and what they understand and what they doubt about the concept of the material during the learning process.

4) Learning Community

This stage is expected to allow students to acquire information through collaborative group learning, with sharing among students and between groups. Study groups at each meeting are composed of the same students, arranged heterogeneously. At the first meeting, students adjust their study groups. However, in subsequent meetings, up to the final meeting before the lesson begins, students are instructed to frequently discuss difficult material. This builds students' confidence in their own knowledge and encourages them to collaborate in group learning to solve problems.

Students exchange information, think collaboratively, and work collaboratively in groups. This impacts some passive students, allowing them to become immersed in the learning and become cognitively involved, fostering positive individual engagement. At this stage, students are also instructed to solve problems provided

in worksheets (LKS), such as finding the surface area and volume of flat-sided geometric shapes.

5) Modelling

This modeling is a concrete stage, there is a real example that can be seen in its form or a picture of the material in question and students observe the available objects and geogebra that has been displayed in the LKS and Teaching Materials and students are invited to make and cut the nets that they have made.

6) Reflection

This stage is an evaluation stage, where students reflect on what they have learned and express it in a concept. The teacher asks students to present or express the results of their worksheets with their groups and summarize the lessons that have been taught and add to or correct the opinions that students have expressed.

7) Authentic Assesment

Authentic assessment itself is a collection of student learning experiences, demonstrating that students have learned well and can understand mathematical concept modeling and contextual problems in everyday life. Assessment at this stage is viewed individually, and includes student activity during the learning process, their ability to socialize in groups, and their final cognitive outcomes. This stage also determines student abilities, where some students are able to fully understand the material presented.

After carrying out the stages of the contextual approach in the closing activity, the teacher provides a conclusion regarding the material taught at this meeting and evaluates, notes the shortcomings found that day and improves them in the next meeting and closes the learning by reflecting, appreciating the learning that has taken place, and motivating students to remain enthusiastic in learning and praying together.

3. Students' Creative Thinking Ability Using Contextual-Based Teaching Materials Assisted by GeoGebra AR

Based on observations during the learning process and an analysis of students' mathematical creative thinking scores, a general description can be drawn regarding the development of students' abilities after using contextual-based teaching materials assisted by GeoGebra AR. At the beginning of the meetings, students appeared to need time to adjust to the new learning model. This is reasonable because their previous learning experiences were dominated by the scientific approach. However, starting from the second to the sixth meeting, students began to show increased participation and were able to follow context-based learning and the use of GeoGebra more fluently.

Descriptively, students' mathematical creative thinking ability was analyzed through four indicators: originality, flexibility, elaboration, and fluency. The average scores and achievement percentages of students in the experimental class (contextual approach assisted by GeoGebra AR) consistently showed higher values compared to the control class (scientific approach). A summary of achievements for each indicator is presented below:

Table 5. Summary of Item Scores for Students' Mathematical Creative Thinking Ability Experimental Class & Control Class

No	Indicator	Item	Maximum Ideal Score (MIS)	Scientific Approach		Contextual Approach Assisted by GeoGebra	
				$\bar{x}$	%	$\bar{x}$	%
1	Constructing various methods to determine the surface area of three-dimensional flat-sided solids (Originality)	3	14	8,74	62 %	10,97	78%
2	Formulating mathematical ideas from contextual problems presented in the form of word problems (Flexibility)	2	12	7,33	61%	9	75%
		5	16	10,13	63%	12,68	79%
3	Developing methods for solving mathematical problems (Elaboration)	1	10	6,3	63%	7,63	76%
4	Providing alternative solutions to mathematical problems fluently (Fluency)	4	12	9	75%	11	92%

a) Originality

Students demonstrated better ability in generating various methods to determine the area of quadrilaterals. The average percentage in the experimental class reached 78%, surpassing the control class which achieved 62%.

b) Flexibility (Ability to generate multiple mathematical ideas)

For the indicator involving the formulation of ideas from contextual problems, the experimental class scored 75%, while the control class achieved 61%. In another item under the same indicator, the experimental class obtained 79% compared to 63% in the control class.

c) Elaboration

The ability to develop and expand mathematical problem-solving strategies in the experimental class reached 76%, higher than the control class which achieved 63%.

d) Fluency

In the indicator assessing students' ability to provide alternative solutions fluently, the experimental class achieved 92%, significantly higher than the control class which scored 75%.

When compared with the minimum mastery criterion (KKM) of 75%, most indicators in the experimental class exceeded this threshold, whereas the control class remained below it for almost all indicators. This indicates that the use of contextual-based teaching materials assisted by GeoGebra AR contributes positively to enhancing students' mathematical creative thinking abilities.

Overall, the descriptive data indicate that learning supported by GeoGebra AR within a contextual approach helps students better understand context-based problems, generate more varied ideas, and solve problems more fluently and thoroughly than the scientific approach used in the control class.

e) AR-Based Product Access Links

As part of the final output of the developed teaching materials, students are provided with access to GeoGebra Augmented Reality (AR) models that allow them to visualize and manipulate 3D solid shapes directly through their mobile devices. The interactive AR models for cubes and other flat-sided geometric solids used in this study can be accessed through the following link:

a) GeoGebra AR Model Collection:

<https://www.geogebra.org/search/kubus%20AR>

This link contains several AR-based 3D models that students can scan, rotate, enlarge, and explore in real-world space using their smartphones. The same link and QR codes have been embedded in the worksheets to ensure easy access during classroom learning activities.

In addition to the AR models, the complete teaching materials—including the Student Worksheet (Lembar Kerja Peserta Didik / LKPD)—are publicly accessible through the link below:

b) Teaching Materials & LKPD Collection (Google Drive):

https://drive.google.com/drive/u/0/folders/1oEc_z4FX9Yd28ZKA7lDAyU2eGvHH6LN2

This folder contains the finalized version of the LKPD, interactive worksheets, and supporting materials used in classroom implementation. These resources are designed to guide students through contextual learning activities and to support exploration using GeoGebra AR.

The combined use of AR objects and contextual worksheets significantly supports students' spatial reasoning and creative thinking processes by enabling direct, interactive visualization of geometric elements such as edges, vertices, faces, and nets. These digital resources strengthen students' understanding through hands-on manipulation, problem-solving activities, and real-world contextual tasks.

Discussions

The development process carried out through the ADDIE stages resulted in teaching materials that were declared highly valid and practical by both material and ICT experts. The high validation scores (material expert = 94.43%; ICT expert = 92.41%) indicate that the structure, content appropriateness, visual design, and technological integration of GeoGebra AR meet the criteria for high-quality digital mathematics teaching materials.

These findings reinforce previous studies, such as Lestari (2018) and Amelia & Ningsih (2020), who argue that well-designed teaching materials can significantly enhance students' conceptual understanding. The present study extends these findings by incorporating Augmented Reality into a contextual learning framework, resulting in teaching materials that not only meet pedagogical standards but also leverage immersive technology to support visualization.

In addition, the practicality test results (95.10% in the wide trial) demonstrate strong student acceptance. This supports the findings of Sari (2024), who states that digital and interactive

learning environments increase student engagement, curiosity, and motivation. Similarly, the present research shows that students found GeoGebra AR-based teaching materials easy to use, attractive, and helpful for understanding spatial concepts that previously seemed abstract when learned only from textbooks.

Therefore, this development aligns with prior research indicating that teaching materials enriched with technology and designed with clear pedagogical strategies can enhance both usability and learning impact.

The learning process in the experimental class followed the seven components of the Contextual Teaching and Learning (CTL) approach: constructivism, inquiry, questioning, learning community, modeling, reflection, and authentic assessment. The implementation aligned well with Afriani (2018), who emphasizes that CTL structures learning so students can build their own knowledge through real-world exploration.

The use of GeoGebra AR strengthened the inquiry and modeling steps, enabling students to visualize and manipulate 3D objects directly, which is consistent with findings by Sirakaya & Cakmak (2018) and Suh & Prophet (2018) that AR significantly improves spatial reasoning, motivation, and conceptual understanding. Students were able to interact with virtual cubes, prisms, and pyramids, making the concept of edges, vertices, faces, nets, and volume more concrete. This study further supports Haqq & Toheri (2019), who noted that visualization is one of the main barriers in geometry learning. By integrating AR, students overcame these barriers through active manipulation of 3D objects rather than relying solely on 2D images.

Moreover, the collaborative group-based learning implemented in the learning community stage aligns with Ulimaz et al. (2024), who argue that collaborative and game-like learning environments increase motivation and achievement. In this study, AR-based exploration encouraged students to discuss, predict, test, and verify ideas collectively, enriching their learning experience. Thus, the implementation of GeoGebra AR within a CTL framework not only aligns with the theoretical foundations of constructivist learning but also complements and extends the practical findings of earlier studies on digital learning tools in mathematics.

The results show a substantial improvement in students' mathematical creative thinking abilities across all four indicators defined by Torrance (1974): fluency, flexibility, originality, and elaboration. The experimental class consistently outperformed the control class, with the highest gain occurring in fluency (92%) and originality (78%). These findings align strongly with the literature. According to Jones et al. (2020), the major difficulty students face in geometry is related to spatial visualization and generating multiple solutions. GeoGebra AR directly addresses this by offering dynamic and interactive views of geometric shapes. Similarly, Diva et al. (2023) and Yerushalmy & Shternberg (2020) reported that dynamic digital environments like GeoGebra allow students to test hypotheses, discover patterns, and produce creative mathematical reasoning.

The contextual tasks embedded in the worksheets ensured that students were not only manipulating shapes but also connecting them to real-life applications. This supports Rahmawati & Kartono (2021), who found that contextual teaching materials improve students' flexibility and ability to formulate mathematical ideas. In the present study, flexibility reached 75%–79%, indicating that students were able to propose diverse strategies and interpretations. The elaboration indicator also increased significantly (76%), which is consistent with Amelia & Ningsih (2020), who observed that exploration-based materials encourage students to refine and detail their ideas more effectively. Overall, the results imply that combining contextual learning with AR strengthens all aspects of creative thinking. AR improves visualization and exploration, while the contextual approach connects learning to meaningful real-world contexts. This dual reinforcement system enhances students' ability to generate ideas, choose

effective strategies, propose unique approaches, and articulate detailed reasoning. Thus, this study not only confirms prior findings but also provides a clearer empirical picture of how CTL and AR can work synergistically to improve mathematical creative thinking.

CONCLUSION

This study developed and implemented contextual-based teaching materials assisted by GeoGebra Augmented Reality (AR) for the topic of flat-sided solid geometry. The findings from the validation, practicality, and learning implementation indicate that the developed materials meet the criteria of being highly valid, practical, and effective.

First, the teaching materials produced through the ADDIE development stages demonstrated very high validity, supported by expert evaluations in both content and technological aspects. This indicates that the integration of contextual learning components with AR-based visualization successfully produces materials that are pedagogically sound, relevant, and aligned with curriculum standards.

Second, the practicality test results from the limited and wider trials show that the teaching materials are easy to use, visually engaging, and supportive of student learning needs. Students responded positively to the use of GeoGebra AR, highlighting its clarity, interactivity, and ability to help them visualize three-dimensional objects more concretely.

Third, the implementation of these materials significantly improved students' mathematical creative thinking abilities. Improvements were observed across all indicators—fluency, flexibility, originality, and elaboration—showing that the combination of contextual tasks and interactive AR environments provides meaningful cognitive support. Students were able to generate more ideas, consider diverse strategies, formulate unique solutions, and elaborate their reasoning with greater detail.

Overall, this research concludes that contextual-based teaching materials supported by GeoGebra AR are effective in enhancing students' understanding and creative thinking in flat-sided solid geometry. The integration of real-world contexts with immersive technological visualization allows students to explore mathematical ideas more deeply and intuitively.

In addition, this study contributes to the existing literature by demonstrating that contextual learning and AR technology can work synergistically to overcome visualization barriers, increase engagement, and promote higher-order thinking skills in geometry. Future research may extend these materials to other mathematical topics or explore their use with larger and more diverse student populations to further validate their effectiveness.

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