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Development of Geogedu Game on Curved Shapes to Improve Conceptual Understanding and Spatial Ability

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A B S T R A C T
This study aims to determine the validity, practicality, and effectiveness of Geogedu, an educational game designed to enhance students' conceptual understanding and spatial abilities. The development of Geogedu was driven by the need for innovative media to address students' difficulties in visualizing spatial concepts and curved shapes. Developed using MIT App Inventor, Geogedu integrates interactive features to support engaging learning. The development process followed the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). In the Development phase, expert validation resulted in a score of 3.2 (quite valid), and a limited trial assessed usability and functionality. During the Implementation phase, Geogedu was tested on 35 students of Grade IX at SMP BP Maarif Assaadah to evaluate its practical use in a real classroom setting. The practicality score was 3.45 (practical), and the N-gain score was 0.45, indicating medium effectiveness. These findings suggest that Geogedu is a valid, practical, and moderately effective learning media that can be used in classroom instruction to improve students' conceptual understanding and spatial abilities.

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1. INTRODUCTION

In the current digital era, integrating technology into education has become essential to enhance student engagement and learning outcomes. One effective approach is the use of educational games, which combine students' interest in interactive media with instructional content. Games are not only favored by young people but even the elderly and early childhood. In this technological era, games are easily accessed with a smooth internet network. To play games does not require complicated equipment, just a cell phone or computer whose existence is very easy to find. The study revealed a significant and positive impact of gamification on students' achievement across various factors, including geographical regions, education levels (Ortiz et al, 2025), learning environments, subjects and game elements. Implications for practice gamification represents a prudent choice for teachers seeking to enhance students' achievement. Teachers are suggested to adopt and employ appropriate game elements in their instructional approaches (Zeng et al., 2024).

One way that mathematics teachers can make abstract or difficult material more understandable is by using educational games that are strategically aligned with learning objectives. These games serve as interactive tools that transform passive learning into active exploration, encouraging student motivation, engagement, and deeper understanding. In addition to understanding the material, math games will also reduce the fear and boring impression experienced by students towards math (Weningsari et al., 2014).

The current era of technology also strongly supports educators to be able to develop their own games in accordance with the learning objectives to be achieved. One application that is easy to use and free is MIT App Inventor. MIT App Inventor is an application that allows users to create software applications for android without having to bother learning coding first (Saputra et al., 2024). This MIT App Inventor has two main parts, namely App Inventor Designer and Block Editor. App inventor designer is a part of MIT App Inventor that is useful for adding components and designing user interface layouts. The MIT App Inventor designer runs in a web browser (web-based) and there is a component palette that displays a collection of basic user interface components such as buttons, labels, and text boxes. To add components, users can simply drag and drop components into the project. The Block Editor is a part of the app inventor for designing programming logic for components that have been previously created in the app inventor designer. In the Block Editor, users can combine related blocks of code. The blocks are located in the drawers on the left side of the Block Editor interface. The user only needs to drag the blocks in the drawers into the workspace in order to add them to the project.

Curved spaces, which include tubes, cones, and spheres, are one of the important geometry materials in the junior high school mathematics curriculum. This material requires students to understand the conceptual of surface and volume in a three-dimensional context, which is often abstract and complex. Research shows (Marasabessy et al., 2021) that many students still have difficulty naming the elements of curved spaces and applying the right formula to calculate surface area and volume, due to the lack of interest and the dominant use of the lecture method in learning.

Numerous researchers have agreed that spatial ability is the core capability of various subjects, such as mathematics, science education, graphics, and physical education. The importance of spatial ability is highly emphasized in certain professional fields which require the visual spatial processing (Lowrie & Logan, 2023). Understanding of curved spaces also requires students to have good spatial abilities, which is visualize, manipulate, and understand the relationship between objects in space. However, many students exhibit underdeveloped spatial skills due to conventional instructional approaches that rely heavily on symbolic and procedural teaching, with minimal use of visualization, interaction, or spatial exploration (Fitriyani & Tasu'ah, 2014; Uttal & Cohen, 2012). This is especially evident in topics involving curved shapes, which are often abstract and challenging for students to comprehend using static, textbook-based representations alone (Ndlovu & Brijlall, 2015).

These limitations in traditional learning environments contribute to persistent difficulties in building deep conceptual understanding in geometry (Presmeg, 2006). Therefore, there is an urgent need for innovative, technology-integrated media that promote active engagement with spatial forms. Educational games, particularly those designed for mobile platforms, offer an effective way to support spatial reasoning and geometric visualization (Boaler, 2016; Pribyl et al., 2020).

In response to this need, this study focuses on the development of Geogedu, a game-based learning application targeting the topic of curved shapes to enhance students' conceptual understanding and spatial ability. The integration of games in learning is proven to increase student motivation and engagement. A study conducted by Makarim et al. (n.d.) found that game-based learning significantly increased students' learning motivation and math learning outcomes.

In addition, the use of games to improve learning outcomes also has a large effect on student math learning outcomes, especially at the elementary school level with an effect size of 1.381. With a fun and contextualized learning atmosphere, educational games can facilitate conceptual understanding because they use real-world situations.

Math educational games, especially those based on three-dimensional geometry, are also proven to be able to develop students' spatial abilities. Research (Wahyudi & Arwansyah, 2019) shows that Augmented Reality-based media can improve students' visual spatial intelligence. Similarly, the use of computer-based interactive learning media in learning geometry has a positive effect on improving students' spatial abilities (Kamid et al., 2021). In other words, the development of educational games on curved space building material is not only relevant to improve understanding of mathematical conceptuals, but also has an impact on other cognitive aspects such as spatial abilities. Several development studies have adapted games for curved-sided space building materials. (Rafanti et al., 2023) developed the game "Math-Village" with the ADDIE model, whose validity was declared 72-78% by experts and its practicality obtained very good responses from students (87.95%). However, most of these studies still focus on product feasibility and user response, without exploring how game mechanisms can strengthen students' understanding of mathematical conceptuals and develop their spatial abilities. Spatial Visualization is one of the spatial ability types. It refers to the ability to mentally manipulate and understand spatial relations between objects in the physical environment. This skill is necessary for various tasks such as reading maps, understanding directions, and solving complex problems in subjects like mathematics and science.

Based on the explanation above, it is necessary to conduct research that not only develops educational games, but also examines in depth their effect on students' conceptual understanding and the development of their spatial abilities on curved space materials. Various studies have shown that educational games and interactive digital media can significantly enhance students' engagement and learning outcomes in mathematics. For example, Rafanti et al. (2023) developed the "Math-Village" game using the ADDIE model and reported high levels of validity (72–78%) and very positive student responses (87.95%). However, such studies have primarily focused on aspects of product feasibility, validity, and practicality, while neglecting deeper evaluations of the impact of game mechanics on students' cognitive development, particularly in terms of conceptual understanding and spatial ability.

Similarly, the works of Wahyudi & Arwansyah (2019) and Kamid et al. (2021) confirmed that the use of Augmented Reality and interactive computer-based media can improve students' spatial intelligence. Yet, these studies tend to emphasize technological novelty rather than systematically measuring how educational games support spatial reasoning, especially the spatial visualization required in learning three-dimensional curved shapes such as spheres, cones, and cylinders.

Moreover, while educational games are widely recognized for increasing motivation and engagement (Boaler, 2016; Makarim et al., n.d.), many studies fail to link game elements—such as real-world context, feedback systems, and visualization tasks—with specific learning objectives in geometry. As a result, there is limited evidence on how game-based learning can directly influence students' conceptual mastery of curved shapes, a topic that is often abstract and difficult for junior high school students to grasp.

In addition, most game development studies rely on advanced programming platforms, limiting their accessibility for educators. There is a lack of research utilizing user-friendly platforms like MIT App Inventor, which enable teachers to develop mobile learning games tailored to classroom needs without programming skills.

Therefore, this study seeks to address these gaps by developing Geogedu, an educational game created using MIT App Inventor, with a specific focus on the topic of curved shapes. Unlike previous works, this research not only measures the validity, practicality, and effectiveness of the game but also evaluates its impact on students' conceptual understanding and spatial visualization ability. By integrating educational game design principles into a structured ADDIE development framework, Geogedu aims to offer both a pedagogically effective and technically accessible solution for learning geometry in the digital era.

By designing game elements that stimulate motivation, real context, shape visualization, and collaboration between students, it is hoped that this game can be an effective learning media in overcoming conceptual difficulties and improving students' spatial abilities.

2. METHOD

This research was conducted using the ADDIE development model (Analysis, Design, Development, Implementation, Evaluation) (Sugiyono, 2015). The research was conducted at SMP BP Maarif NU Assaadah Bungah Gresik. The implementation involved 35 students from grade IX selected through purposive sampling based on their varied mathematical abilities (high, medium, and low achievers. The research was conducted over four meetings. A pretest is conducted before starting the lesson, and a posttest is given after the lesson is completed. The time required to complete the test is 60 minutes. The pretest and posttest questions are equivalent.

The pretest and post-test contain 6 questions of conceptual understanding and 4 questions of conceptual understanding containing spatial visualization. One mathematics teacher with 10 years of teaching experience participated as the implementer and evaluator of the Geogedu learning media.

The research instruments used were 1) validation sheet, 2) teacher response questionnaire and student response, and 3) learning outcome test used to measure the effectiveness of Geogedu in conceptual understanding and spatial ability of students.

The validity analysis was obtained based on the results of expert validation, which is material experts and technology experts. Data in the form of suggestions and comments were analyzed qualitatively, while the assessment data were measured on a Likert scale and analyze the score using excell. The scoring criteria are as follows. The following are the criteria for product validity (Wibowo, 2017).

Table 1. Criteria of Validity

Validity Score	**Category**
$x > 4{,}206$	Very valid
$3{,}402 < x \leq 4{,}206$	Valid
$2{,}598 < x \leq 3{,}402$	Valid enough
$1{,}794 < x \leq 2{,}598$	Less valid
$x \leq 1{,}794$	Invalid

The following is the formula for the average validity score.

$$x = \frac{total\ score}{number\ of\ items}$$

Practicality analysis was obtained through teacher response questionnaire and student response. The teacher response questionnaire was given to the subject teacher. The student response questionnaire was given to students who participated in the implementation phase. All the data were analyze using spss. The criteria for practicality can be seen in the following (Wibowo, 2017).

Table 2. Practically Criteria

Practicality Score	**Category**
$x > 4{,}206$	Very practical
$3{,}402 < x \leq 4{,}206$	Practical
$2{,}598 < x \leq 3{,}402$	Practical enough
$1{,}794 < x \leq 2{,}598$	Less practical
$x \leq 1{,}794$	Not practical

The following is the formula for the average practically score.

$$x = \frac{total\ score}{number\ of\ items}$$

The analysis of the effectiveness of Geogedu is obtained from the results of the achievement of learning objectives seen from each conceptual understanding and spatial ability of students on the material of the curved space using the N-Gain method (Hake, n.d.). The effectiveness criteria can be seen in the following table:

Table 3. N-Gain Value Criteria

N-Gain Value	Criteri
N-Gain > 0.70	High
0.30 <N-Gain ≤ 0.70	Moderate
N-Gain ≤ 0.30	Low

The following is the N-gain formula

$$N - gain = \frac{post\ test\ score - pre\ test\ score}{maximum\ possible\ score - pre\ test\ score}$$

3. RESULTS AND DISCUSSION

3.1 Analyze Stage

The analysis conducted in this study includes an analysis of the learning curriculum used in schools, an analysis of the learning situation, and an analysis of student characteristics. The curriculum used is independent curriculum with the use of teaching modules as a learning reference. The teaching module used by the teacher in learning curved spaces only uses LKPD (task paper) and power point learning media to teach material to students. From the analysis of learning resources used for curved space material, there are several types of volume and surface area formulas that must be memorized by students. The learning resources used also use problems that are only in the stage of applying simple surface area and volume formulas, not problem solving problems or problems that require HOTS. From the results of observations of learning and interviews with the teachers, students tend to be passive, listening to the teacher's explanation then taking notes and trying to do practice problems. The learning process is also still teacher centered, so the feedback given by the teacher to the students and vice versa is still lacking. The use of power point to show pictures and formulas of curved spaces also does not get a positive response from students. From the results of diagnostic tests conducted at the beginning of the grade, most students has a visual and kinesthetic learning styles. The interests of most students also show that they prefer tactile activities (hand skills) and outdoor activities (sports).

3.2 Design Stage

The design stage is done by designing a storyboard that will be displayed in Geogedu. The storyboard tells about the journey of the main character to complete the mission. On his way he must complete the obstacles encountered in order to open the door to enter the next level until he reaches the final goal of the mission. The obstacles encountered along the way are in the form of tasks related to curved spaces, starting from simple tasks to tasks with solutions that require higher-level thinking skills (HOTS). The storyboard outlines the progression of the learning content in a mission-based format, where each level represents specific conceptual challenges such as identifying elements of curved shapes, calculating surface area and volume, and solving contextualized problems. These levels were designed in accordance with cognitive development principles, referring to Bloom's Taxonomy, with a focus on higher-order thinking skills.

To support interactive learning, a user-friendly interface was planned using MIT App Inventor. This included designing the layout of the home screen, level menus, game missions, and feedback components, such as visual cues for correct or incorrect answers. Game navigation was also mapped to facilitate intuitive transitions between tasks. Game mechanics were selected not only for engagement but also to reinforce cognitive goals (unlocking a virtual gate by solving a geometry problem or completing a bridge challenge using spatial visualization strategies). Tasks within the game involved conceptual understanding questions such as net-shape matching, real-world volume calculations, and identifying rotated objects, all embedded in gameplay scenarios.

3.3 Development Stage

At the development stage, the realization of the storyboard that has been made will be carried out and then validated by experts to see the shortcomings and weaknesses of Geogedu that must be corrected. The first validator was a lecturer in Mathematics Education at the University of Qomaruddin, with expertise in geometry and pedagogical design. The second validator was a lecturer in Information Technology at the same university, with specialization in software development. The validation process involved the use of structured validation sheets based on Likert-scale indicators, assessing content relevance, clarity of instructions, interface design, interactivity, and alignment with learning objectives. Both validators provided suggestions for improvement, which were incorporated into the next stage of development. Geogedu was made with the MIT App Inventor application which can be used for free via the web. Each interface is designed to be attractive so that it can increase the enthusiasm of students when using Geogedu to learn. Here is an example of the interface in Geogedu.

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Figure 1. Geogedu interface

From the results of expert validation, an average score of 3.2 was obtained, which was quite valid. From the results of expert validation obtained input for the use of thematic backgrounds in accordance with the content of the story on the storyboard. The validator also suggested that as much as possible not to bring up images of curved spaces in the mathematical version but to use the appearance of curved spaces that are appropriate in real-world conditions. The disadvantage of using MIT App Inventor in the creation of Geogedu is the limited size of the game that can be created so that the number of interfaces and the use of audio in Geogedu must be limited in a such a way.

3.4 Implementation Stage

The implementation stage was carried out at SMP BP Maarif NU Assaadah. Students who participated were 35 students from grade IX. The implementation of the Geogedu media at SMP BP Maarif NU was directly aligned with the findings from the needs analysis conducted in the initial phase of the ADDIE model. Based on teacher interviews and student diagnostic assessments at this school, it was found that a significant number of students struggled with conceptual understanding of curved shapes (cylinders, cones, and spheres) and lacked the spatial visualization skills needed to interpret and manipulate these 3D objects. These difficulties were compounded by the predominantly lecture-based teaching model used in geometry lessons, as well as limited availability of interactive or visual learning media. Furthermore, the school showed readiness for digital implementation, as most students had access to smartphones or digital devices and basic digital literacy skills, making them ideal participants for testing a mobile-based learning game.

The implementation of this stage is done by coordinating with the mathematics teacher who teaches in class IX to use Geogedu as a learning media in the teaching and learning process carried out by the teacher on the material of curved space. Before teaching the curved space material, students are given a pretest then at the end of learning the curved space material students do a post-test. The pretest and post-test contain 6 questions of conceptual understanding and 4 questions of conceptual understanding containing spatial visualization.

From the practicality results, a response of 3.45 was obtained which was included in the practical criteria. The following is a table of the results of a questionnaire on the practicality of using Geogedu, which was given to 35 ninth-grade students.

Table 4. Practically Questionnaire Result

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Practicality	35	.70	3.10	3.80	3.4486	.02938	.17383	.030	.150	.398	-.707	.778
Valid N (listwise)	35											

While on the conceptual understanding test and students' spatial abilities, the average N- Gain value obtained is 3.45 which is in the moderate effectiveness criteria. The following is a graph of the pre-test and post-test scores and the average N-gain scores of 35 ninth-grade students.

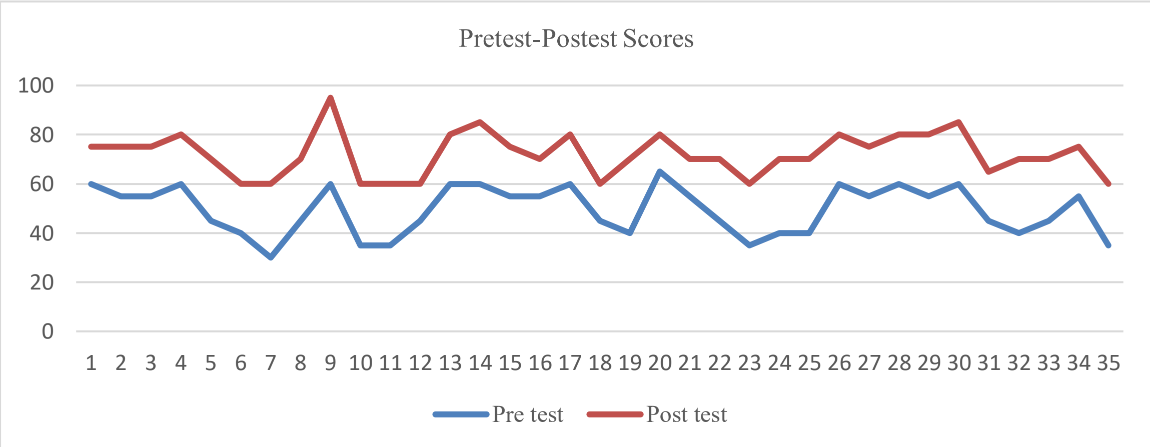

Figure 2. Pretest-Postest Score

The average n gain obtained by students from the analysis of pretest and posttest scores using spss was in the moderate effectiveness range, at 0.45.

Table 5. N-Gain

	N	Range	Minimum	Maximum	Sum	Mean		Std. Deviation	Variance	Skewness	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error
ngain	35	.60	.27	.88	15.90	.4543	.01856	.10980	.012	1.564	.398
Valid N (listwise)	35										

From the results of the development of Geogedu which aims to improve the understanding of conceptuals and spatial abilities of students, it is found that the use of games as learning media is considered valid, practical and effective. The validity value given by the validator is an average of 3.2 which is in the criteria quite valid. This shows that from the aspects of material content, visual appearance, and technical aspects of the Geogedu program has met most of the eligibility criteria. However, the validity score that is still not optimal shows that there are some aspects that can still be improved, such as improving the quality of graphics and enriching the variety of questions in the game. The shortcomings of Geogedu are also due to the limited size of the game that can be made using the MIT App Inventor application.

The average value of practicality obtained from the results of the student response questionnaire of 3.45 shows that Geogedu is easy to use by students and in accordance with the learning context. Students can operate Geogedu without any technical obstacles such as complicated instructions so that students' attention can be fully focused on learning. The ease of accessibility of navigation buttons, menus, and interesting game flow contributed greatly to the practicality score. This is actually an important concern that must be considered by educational game developers in the future because learning media should be able to help not even burden the teaching and learning process carried out in the classroom.

Furthermore, the effectiveness of using Geogedu to improve students' conceptual understanding and spatial ability was measured by comparing the pretest and posttest scores given to the 35 students. From the statistical analysis, the average N-gain value of students was 0.45. This shows that Geogedu succeeded in encouraging a significant increase in learning outcomes but there is still potential for improvement in the learning process in order to get a high N-Gain value. The increase in N-Gain of 0.45 shows that Geogedu is quite effective in clarifying the conceptual of curved-sided spaces, especially on the conceptual of surface area and volume. Because Geogedu combines object manipulation to stimulate 3D perspective, students can more easily imagine the slices and rotations of curved-sided spaces. From the results of conceptual understanding tests and spatial ability tests, the use of Geogedu shows an improvement in student understanding. Interactive visualization in Geogedu makes it easier for students to imagine the spatial structure of curved figures and understand complex calculation steps. The use of spatial manipulation in the images for the tasks that appear in Geogedu also makes students perform visual manipulations such as rotating and projecting curved shapes imaginatively to solve problems. The use of visual manipulation in the tasks given in Geogedu indirectly makes students have to be able to combine the understanding of the conceptual of curved space and the spatial visualization to rotate and project the space according to the problem given.

The problem of students' difficulty in visualizing spatial shapes can also be improved with the use of Geogedu, where in the given task the shape of the curved of the spatial shape appears in an imperfect/tapered form or also in the form of a projection of the shape.

When compared with similar studies, the results of this research align with the findings of Makarim et al. (2023), whose meta-analysis showed a significant positive effect of game-based learning on students' mathematics achievement and motivation. Similarly, Wahyudi and Arwansyah (2019) found that the use of augmented reality in geometry improved spatial reasoning. However, other studies have reported more modest gains. For instance, Rafanti et al. (2023), in their development of the “Math-Village” game, noted high student engagement and positive perceptions, but only limited improvement in test scores, suggesting that engagement alone does not guarantee conceptualual mastery.

These variations in findings across studies may stem from differences in game design, target conceptuals, duration of exposure, and evaluation methods. For example, research that used 3D interactive environments or AR-based tools often reported stronger effects on spatial ability compared to 2D games like GeoGedu. Conversely, 2D games may be more accessible and easier to integrate into traditional classrooms, thus offering broader scalability despite potentially smaller cognitive gains.

4. CONCLUSION

Based on the overall research findings of the development of Geogedu learning media which is developed for free through the web using the MIT App Inventor application, it appears that the use of Geogedu supports the learning process of mathematics on the material of curved space. Although the validity of Geogedu is classified as sufficient (3.2), the practicality (3.45) and effectiveness with N- Gain value (0.45) show that the use of Geogedu learning media as a tool in the teaching and learning process in the classroom can be used well, the research is not without its limitations. The validity of the media, which is still categorized as “fair,” suggests that improvements are needed in content design, user interface, and the complexity of the problems presented. Moreover, the limited number of participants from a single class and the short duration of the trial may restrict the generalizability of the results. The use of instruments that did not fully isolate the game’s effect on spatial ability also opens the possibility of other biases, such as students’ intrinsic motivation or teacher influence during implementation.

Therefore, future studies are recommended to involve larger and more diverse samples across multiple schools and to extend over a longer period to allow for longitudinal observations of the media’s impact. Trials should also include more specific instruments to assess spatial ability, such as mental rotation tests or 3D object visualization assessments, and compare the effects of GeoGedu with other instructional media through experimental approaches. In addition, integrating technologies like Augmented Reality or basic 3D manipulation features could serve as the next step in enhancing spatial visualization.

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