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Design and evaluation of a mobile application for achieving computational thinking skills through geometric transformation learning in middle school

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Abstract

Several studies indicate that students frequently make errors when determining the resulting reflection of geometric transformations. On the other hand, several studies mention that mobile applications have been proven effective in reducing conceptual errors in learning geometric transformations. Additionally, some experts argue that computational thinking is a skill students need to master, and it is on par with reading, writing, and arithmetic. Therefore, this study aims to design and evaluate a mobile application specifically developed to support the achievement of computational thinking skills by learning geometric transformations in middle school. The method used was Research and Development (R&D), which begins with a development stage involving needs analysis, learning material and curriculum analysis, and application design. The evaluation phase involved testing the application's validity, practicality, and effectiveness on 51 ninth-grade students from two different schools in Indonesia. The research findings indicate that: (1) the developed mobile application was proven valid based on aspects of material, language, and media feasibility; (2) the developed mobile application was proven effective in achieving middle school students' computational thinking skills with student average scores exceeding the minimum passing grade; (3) the developed mobile application was proven practical based on student response questionnaire results. These research results contribute to developing mobile applications in mathematics learning to achieve higher-order thinking skills among students.

Keywords:
Computational thinking, Geometric transformation, Middle school students, Mobile application

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1. INTRODUCTION

Geometric transformation is a fundamental area of study that examines changes in the position, size, and shape of a geometric object (Bagdasar, 2013; Uygun, 2020). There are several types of geometric transformation, including translation, reflection, rotation, and dilation. A strong grasp of these concepts is crucial, enabling students to apply them in diverse fields such as architecture and civil engineering for designing building structures (Leopold, 2020). Furthermore, geometric transformation provides a foundation for success in advanced mathematics, as they are closely related to the concepts of functions and congruence (Avcu & Çetinkaya, 2019; St. Goar & Lai, 2021). Given its importance, geometric transformation are a mandatory component of the secondary school curriculum in Indonesia, beginning in grade 9.

To study geometric transformation in depth, students need Higher-Order Thinking Skills (HOTS), which involves analyzing, evaluating, and creating skills (Anwar et al., 2023; Safrida et al., 2021). One of the HOTS that educational researchers have widely discussed in recent years is Computational Thinking (CT) (Costa et al., 2017; Gadanidis, 2017; Kalelioglu et al., 2016; Kallia et al., 2021; Pérez, 2018; Salwadila & Hapizah, 2024; Shute et al., 2017; Tang et al., 2019; Zhu et al., 2023). CT is a thinking process that adopts the way of thinking of scientists and software engineers in writing programs (Grover & Pea, 2013; Nurlaelah et al., 2024; Wing, 2006). However, CT is not about coding or using computers but about logical, systematic, critical, and creative thinking in formulating problems and finding solutions (Hsu et al., 2018; Lee et al., 2023; Wang et al., 2009). Experts argue that CT is a crucial competency in the 21st century to solve complex problems, identify patterns, and evaluate solutions critically (Cutumisu et al., 2019; Shute et al., 2017; Tekdal, 2021). Several empirical studies also show that students with good CT skills tend to be more successful in their studies (Lei et al., 2020; Zhang et al., 2023; Zhu et al., 2023). The success of CT has encouraged the Indonesian government to include CT in the education curriculum, thereby demanding effective learning innovations for students' CT skills achievements.

To implement innovation in educational practices, it is essential to consider the characteristics of the material being taught (Mazgon & Stefanc, 2012). The characteristics of geometric transformation material are very dependent on visualization, so students need to have good visual-spatial skills and an understanding of mathematical concepts (Ahmad et al., 2023; Uygun, 2020). However, students often make mistakes when drawing reflections from geometric transformation results (Ansori et al., 2024; Guven, 2012). In addition, most new students have an operational understanding, which is simply following the steps without really understanding the concept in depth (Guven, 2012; Sunariah & Mulyana, 2020). To overcome this problem, some researchers recommend the use of dynamic geometry tools to improve students' understanding from operational to conceptual (Chan & Leung, 2014; Guven, 2012; Zhang et al., 2023).

One of the commonly used dynamic geometry tools is GeoGebra, a dynamic mathematics software that has features for creating and manipulating geometric objects (Andraphanova, 2015; Chan & Leung, 2014; Zhang et al., 2023). GeoGebra can be accessed via computer technology or mobile devices. However, the computer version of GeoGebra offers more complete features than the mobile version. This opens up opportunities to develop mobile-based geometric transformation learning applications that adopt the superior features of the computer version of GeoGebra. Mobile applications also provide live animations for each type of transformation so that students can see the gradual changes better. Furthermore, mobile applications can be developed with an intuitive interface and a directed interaction flow in accordance with curriculum standards and learning objectives, making it easier for students to use the application directly without having to go through a complicated adjustment stage.

The use of mobile applications has the potential to be an appropriate learning innovation for achieving students' CT skills. Several previous studies have also shown the effectiveness of mobile applications in training students' CT skills (Barrón-Estrada et al., 2021; Chookaew & Panjaburee, 2022; Hakiki et al., 2024; Terzopoulos et al., 2021). However, these studies generally focus on programming learning and are not specifically oriented toward mastering geometric transformation material. In addition, the development of mobile applications in several studies has not been optimal in utilizing features such as dynamic simulations, scaffolding, transformation animations, and intuitive interfaces (Baihaki et al., 2022; Simarmata et al., 2024). Most studies tend only to move material from textbooks into applications, so students' learning activities are limited to reading and studying the material without providing the opportunity to construct knowledge meaningfully and hone students' mathematical computational thinking. As a result, mobile applications often only function as a complement to geometric transformation learning, not yet optimally utilized as a tool for achieving students' CT skills. To cover this gap, we conducted a study on the Design and Evaluation of a Mobile Application for Achieving Computational Thinking Skills through Geometric Transformation Learning in Middle School. The research questions of this study are: (1) How is the design process of a mobile application for achieving CT skills in middle school students through geometric transformation learning? (2) To what extent is the developed mobile application valid, practical, and effective in achieving middle school students' CT skills?

2. METHOD

2.1. Research and Development Methodology

This study employed the Research and Development (RnD) method, which aimed to develop a valid, practical, and effective mobile application for learning geometric transformation to achieve middle school students' CT skills. In the development stage, a needs analysis was conducted through surveys, interviews with teachers and students, and an analysis of learning materials and curriculum. The result of this stage was the production of an application prototype that aligned with prevailing educational standards and supported the achievement of students' CT skills.

Meanwhile, the research stage involved testing the application’s validity, practicality, and effectiveness. The application’s validity was tested by validators who assessed the feasibility of the application’s material, language, and media aspects. The application’s practicality was measured through a student response questionnaire. The application’s effectiveness was measured based on the results of the CT skills test administered to students after using the application.

2.2. Participants

The validity testing stage involved five validators who assessed the application's feasibility. Meanwhile, the practicality and effectiveness testing stages were conducted with 51 ninth-grade Junior High School students from two different schools in Indonesia. Selecting students from two distinct schools aimed to enhance the representativeness of the findings and improve their generalizability to a broader population (George, 2021). The total sample size of 51 students was determined based on empirical guidelines in educational research, which recommend a minimum of 30 participants for valid statistical analysis (Besekar et al., 2024). All students voluntarily agreed to participate after receiving explanations about the research objectives and procedures. Schools were selected based on the availability of facilities supporting mobile application-based learning implementation. Throughout the study, all participants were treated ethically in accordance with the standards of the American Psychological Association (1992).

2.3. Instrumentations

This study used test and non-test instruments to answer the research questions. The test instrument was used to test the effectiveness of mobile applications on geometric transformation material for achieving students' CT skills. The non-test instrument was used to test its validity and practicality of the application. The validity of all instruments was calculated using *Aiken's V* formula (1985), with the following interpretation of values: $0 \leq V \leq 0.3$ indicates low validity; $0.3 < V \leq 0.7$ indicates moderate validity; and $0.7 < V \leq 1$ indicates high validity (Aiken, 1985; Hsu et al., 2015).

This test consisted of four descriptive questions that are adjusted to the basic competency standards of junior high school mathematics based on the topic of geometric transformation. The test instrument was developed based on four aspects of computational thinking, namely decomposition, pattern recognition, abstraction, and algorithmic thinking (Wing, 2006). The CT test grid is presented in Table 1.

Table 1. Grid of CT test

Question number	CT aspects measured	Indicators of Competence Achievement
1	Students can identify important information in mathematical problems while ignoring irrelevant information (Abstraction).	Students can solve contextual problems related to dilation.
2	Students can create systematic instructions or stages to solve mathematical problems (Algorithmic Thinking).	Students can solve contextual problems related to translation.
3	Students can break down complex problems into simpler and more manageable ones (Decomposition).	Students can solve contextual problems related to reflection.
4	Students can observe and recognize recurring patterns, similarities, or differences in a mathematical problem (Pattern Recognition).	Students can solve contextual problems related to rotation.

Each CT aspect was assessed using a rubric. Each question represented one aspect and had a maximum score of 25, resulting in a total maximum score of 100. The test instrument was validated by a PhD-level Mathematics Education lecturer specializing in Geometry and Algebra, along with two mathematics teachers holding a Master's in Education and over 15 years of teaching experience. The results of the test instrument validation showed an *Aiken's V* index score of 0.825, which was categorized as high validity.

The non-test instrument consisted of a mobile application validation sheet and a student response questionnaire. It was validated by a mathematics education lecturer who holds a professorship and is an expert in the field of mathematics education research and evaluation, as well as two doctoral candidates in mathematics education who work as mathematics education lecturers.

The mobile application validation sheet was used to test the validity of the mobile application as a whole. This validation sheet consists of 42 statements with a 4-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Agree, 4 = Strongly Agree). The statements in this validation sheet were developed based on the aspects described in Table 2.

Table 2. Aspects of mobile application feasibility

Feasibility	Feasibility Aspect
Material	1. Material aligns with Basic Competencies and Competency Achievement Indicators 2. Material is equipped with mobile-based features 3. Material is presented sequentially and systematically 4. Material can construct middle school students' mathematical knowledge 5. Material can attract middle school students' learning interest 6. Material is easily understood by middle school students 7. Material aligns with middle school students' thinking level
Language	1. Straightforward 2. Dialogical and interactive 3. Material aligns with middle school students' cognitive development 4. Writing and language conform to Indonesia Language rules
Media	1. Menu component layout is considered consistent 2. Menu component layout is considered harmonious 3. Menu typography is easily understood 4. Navigation buttons are easy to click 5. Font conforms to the user's mobile default 6. Font is easy to read 7. Font color is pleasant to view 8. Images conform to the user's mobile default 9. Image quality is good 10. Animations conform to the user's mobile default 11. Animation quality is good 12. Videos conform to the user's mobile default 13. Video quality is good

The validation results of the mobile application validation sheet showed an *Aiken's V* index score of 0.936, which was categorized as high validity. The student response questionnaire was used to test the practicality of the mobile application. This questionnaire consists of 22 statements with a 4-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3

= Agree, 4 = Strongly Agree). The statements in this questionnaire were developed based on the following aspects: ease of use, clarity of instructions, efficiency, relevance of mobile application features to the material, flexibility of use, attractive and focus-supporting design, support for various student ability levels, and minimal technical disruptions. The validation results of the student response questionnaire showed an *Aiken's V* index score of 0.905, which was categorized as high validity.

2.4. Data Analysis Technique

The data analysis technique in this study used a quantitative approach to test the validity, practicality, and effectiveness of mobile applications on geometric transformation material for achieving middle school students' CT skills. The application's validity was assessed through evaluations by several independent experts, with data analyzed using *Aiken's V* formula, with the following interpretation of values: $0 \leq V \leq 0.3$ indicates low validity; $0.3 < V \leq 0.7$ indicates moderate validity; and $0.7 < V \leq 1$ indicates high validity (Aiken, 1985; Hsu et al., 2015).

Meanwhile, the application's practicality was measured through student response questionnaires, analyzed using percentage calculations with interpretation criteria described by Akbar (2013), with the following interpretations: 85% < percentage ≤ 100% indicates very practical; 70% < percentage ≤ 85% indicates practical; 55% < percentage ≤ 70% indicates quite practical; 40% < percentage ≤ 55% indicates less practical; and 25% ≤ percentage ≤ 40% indicates impractical.

Furthermore, the application's effectiveness was measured through a post-test analyzed using a one-sample t-test with a significance level of $\alpha = 0.05$. Before the t-test, data normality was assessed using the Kolmogorov-Smirnov test with a significance value of more than 0.05, so that the normality assumption was met. The one-sample t-test was used because this study only collected post-test data without pre-test data or a control group, which aimed to determine whether the average post-test scores of students were significantly higher than the Minimum Passing Grade of 75.

In addition to the t-test, the effect size was calculated using Cohen's d formula to measure the magnitude of the application's impact on students' CT skills achievement. The interpretation of Cohen's d values is as follows: $0 \leq d < 0.2$ indicates a small effect size; $0.2 \leq d < 0.5$ indicates a small to medium effect size; $0.5 \leq d < 0.8$ indicates a medium to large effect size; and $d \geq 0.8$ indicates a large effect size (Cohen, 2013).

2.5. Hypotheses

Several past studies have shown that students often make mistakes when describing the resulting image of geometric transformation (Ada & Kurtuluş, 2010; Ahmad et al., 2023; Aktaş & Ünlü, 2017; Ansori et al., 2024; Guven, 2012). However, several studies have shown that the use of dynamic geometry tools is effective in reducing errors in understanding geometric transformation because they provide interactive visualization (Kandaga et al., 2023; Panorkou & Maloney, 2015). One potential dynamic geometry tool is a mobile application. Several studies have proven the effectiveness of mobile applications in improving students' problem-solving skills (Lai & Hwang, 2014; Şanal & Elmali, 2023;

Sánchez & Olivares, 2011). Given that CT is a HOTS for complex problem-solving, then some experts argue that CT needs to be mastered by students, just like reading, writing, and arithmetic (Bråting & Kilhamn, 2020; Lu & Fletcher, 2009; Weintrop et al., 2015; Wing, 2006). Therefore, researchers hypothesize that developing a mobile application on geometric transformation material can achieve students' CT skills. The hypothesis can be formulated as follows:

$H_0 : \mu \leq 75$

$H_1 : \mu > 75$

μ represents the average score of students' post-test CT skills.

This study collected only post-test data without conducting a pre-test due to time constraints and school learning conditions that made pre-test administration unfeasible. Additionally, there was a risk of learning bias if students studied geometric transformation material before using the application. Therefore, this study used a score of 75 as the comparison point, corresponding to the minimum passing grade established by the school where the research was conducted.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Development Results

The design of mobile applications on the topic of geometric transformation was carried out through three stages, namely: (1) field studies; (2) analysis of teaching materials; and (3) adjustment to the curriculum. In the field study stage, we involved 33 junior high school students in filling out a needs analysis questionnaire. This questionnaire contained questions about their preferences for mathematics learning media. In addition, we conducted semi-structured interviews with two experienced mathematics teachers to gain in-depth insights into the use of mathematics learning media and the challenges in teaching geometric transformation.

The questionnaire results showed that mobile applications and printed/electronic books were the two learning media most preferred by students. Meanwhile, in the interview results, the teacher revealed that students often had difficulty visualizing and determining geometric transformation results. To overcome this, the teacher stated that mobile applications have the potential as mathematics learning media, especially if equipped with visual simulation features of geometric objects and step-by-step practice questions equipped with constructive feedback.

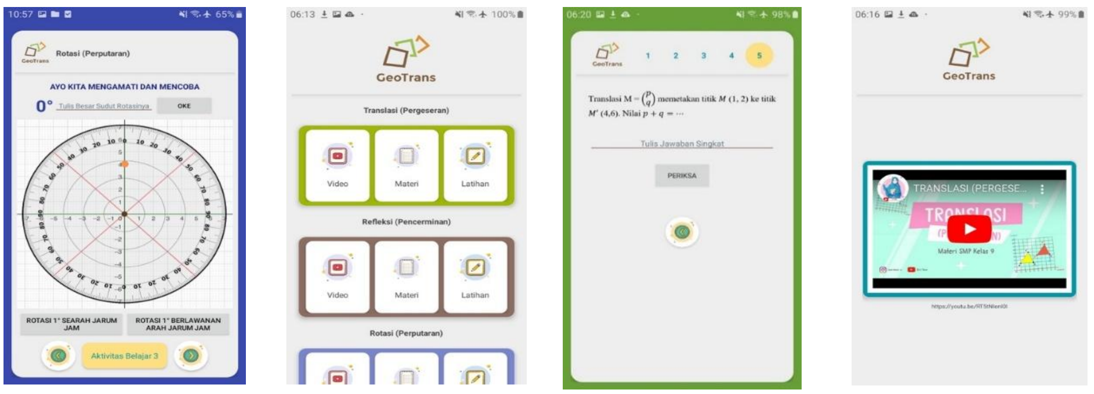
The second stage involved analyzing the instructional materials used, especially textbooks. This analysis revealed several gaps, including: (1) static visualization of geometric transformation; (2) limited interactivity that hinders students' exploration; and (3) lack of exercises that foster CT skills. For example, in textbooks, reflection is visualized as a static image, lacking animations or simulations that enable students to manipulate geometric objects. The mobile application has the potential to address this limitation by providing interactive simulation features that allow students to understand the concept of reflection in real-time, thereby enabling them to construct knowledge about the properties and concepts of reflection, ultimately leading to improved conceptual and procedural understanding.

In the third stage, the application is adjusted to the applicable curriculum, namely Basic Competencies and Competency Achievement Indicators, which are described in Table 3.

Table 3. Basic competencies and competency achievement indicators

Basic Competencies		Competency Achievement Indicators	
3.5	Explain Geometric Transformation (*Reflection*, *Translation*, *Rotation*, and *Dilation)* in connection with contextual problems.	3.5.1	Students can understand and describe the concept of *Translation*.
		3.5.2	Students can understand and describe the concept of *Reflection*.
		3.5.3	Students can understand and describe the concept of *Rotation.*
		3.5.4	Students can understand and describe the concept of *Dilation.*
4.5	Solve contextual problems related to Geometric Transformation (*Reflection*, *Translation*, *Rotation*, and *Dilation*).	4.5.1	Students can solve contextual problems related to *Translation*.
		4.5.2	Students can solve contextual problems related to *Reflection*.
		4.5.3	Students can solve contextual problems related to *Rotation*.
		4.5.4	Students can solve contextual problems related to *Dilation*.

The result of these three stages is a mobile application that has several features, including: (1) interactive simulation that can manipulate geometric objects in real-time (see Figure 1a); (2) material explanation that can construct geometric transformation knowledge (see Figure 1b); (3) gradual exercises with increasing levels of difficulty and equipped with personal feedback (see Figure 1c); and (4) learning videos that explain geometric transformation concepts (see Figure 1d). Overall, the development of this application is intended to address gaps in conventional teaching materials and provide interactive, adaptive, and effective learning media. In addition, it will improve students' understanding of the topic of geometric transformation and develop their CT skills.



(a) (b) (c) (d)

Figure 1. Mobile application prototype

3.1.2. Research Results

Validity of the Developed Mobile Application

Validity testing was conducted by expert validators consisting of: (1) two mathematics education lecturers who are experts in mathematics learning technology, responsible for assessing the feasibility of the material and media in the application; (2) one Indonesian language education lecturer, responsible for assessing the feasibility of the language in the application; and (3) two experienced mathematics teachers (with a minimum of 15 years of teaching experience and holding a Master of Education degree), responsible for assessing the feasibility of the material, language, and media in the application. Table 4 presents the validation results of the mobile application.

Table 4. Results of the mobile application validity test

Feasibility Aspect	*Aiken's V* Value	Validity Category
Material	0.89	Very high validity
Language	0.82	Very high validity
Media	0.89	Very high validity

Table 4 presents the mobile application's validity test results, measured using *Aiken's V*, focusing on three feasibility aspects: material, language, and media. The validation results indicate that the mobile application is highly valid in all three aspects.

In addition to providing quantitative assessments, the validators offered qualitative suggestions to enhance the application's quality. These suggestions include improving the language aspect by using simpler word choices that align with the comprehension level of middle school students, as well as refining the application's design and functionality, such as a more intuitive menu layout, the addition of an interactive drag and drop point feature, and constructive feedback on practice questions. Implementing these suggestions is expected to significantly improve students' learning experience, ultimately positively impacting learning effectiveness. These high-validity results affirm that the developed mobile application has significant potential to achieve students' CT skills through learning geometric transformations.

Practicality of the Developed Mobile Application

The application's practicality was tested through a student response questionnaire. The results of the questionnaire data analysis are presented in Table 5.

Table 5. Results of the mobile application practicality test

No	Practical Aspects	Average Score	Category
1	Ease of Use	86	Very Practical
2	Clarity of Instructions	88	Very Practical
3	Efficiency	85	Practical
4	Relevance of Mobile Application Features to the Material	86	Very Practical
5	Flexibility of Use	82	Practical
6	Attractive and Focus-Supporting Design	83	Practical

No	Practical Aspects	Average Score	Category
7	Support for Various Student Ability Levels	80	Practical
8	Minimal Technical Disruptions	82	Practical

Table 5 shows that the average percentage of all practicality aspects was 84%, indicating a practical category. This result suggests that students consider the developed mobile application practical in supporting mathematics learning, particularly on the topic of geometric transformation.

In addition to student responses, teachers also provided feedback on this application. They stated that the developed application was very helpful in the geometric transformation learning process because it presented contextual learning activities that facilitated students' understanding of abstract material. Furthermore, they appreciated features such as practice questions with answer hints that helped students independently correct their mistakes, as well as material explanation videos and example problems that are very useful as learning resources. Therefore, the positive feedback from teachers confirms the potential of this application as a practical learning medium in studying geometric transformation, as well as indicates that the application can be well integrated with the applicable curriculum.

Effectiveness of the Developed Mobile Application

The effectiveness of the application was tested by administering a CT test after using the mobile application. The effectiveness test used a *one-sample t-test* to determine whether there was a significant difference between students' CT test scores after using the application and the established Minimum Passing Grade value (75). Before conducting the one-sample t-test, a data normality test was first conducted. Given that the number of samples was more than 50 students, the data normality test was conducted using Kolmogorov-Smirnov. Table 6 presents the normality test results with a significance level of $\alpha = 0.05$.

Table 6. Results of the normality test

Statistic	df	$Sig.$
0.064	51	0.200

Based on Table 6, the significance value obtained was 0.064. This value is greater than the established significance level, indicating that students' CT test score data after using the application is normally distributed. Therefore, the normality assumption was met, allowing for parametric statistical analysis.

Furthermore, a one-sample t-test was conducted. The results of the one-sample t-test are presented in Table 7.

Table 7. Results of the *one-sample t-test*

t	df	$Sig.\ (2-tailed)$
3.401	50	0.001

Based on Table 7, the calculated t-value obtained was 3.401, degrees of freedom (df)=50, and significance level (sig)=0.001. Because the alternative hypothesis (H_1) was one-tailed, the one-tailed p-value was 0.0005, which was obtained by dividing 0.001 by two.

Therefore, if the one-tailed p-value was less than 0.05, H_0 was rejected. This result indicates that the average post-test score of students' CT skills was greater than 75. Therefore, the mobile application on the topic of geometric transformation was effective for achieving students' CT skills. However, it does not imply strong causality due to the single-group design.

The effect size of the application's use on students' CT skills was calculated using Cohen's d with an average post-test score of 78.9, a minimum passing grade of 75, and a standard deviation of 8.15; the Cohen's d value was 0.48, indicating a small to medium effect size. This result suggests that the application has an effective and meaningful impact on achieving students' CT skills.

3.2. Discussion

Validity of the Developed Mobile Application

The application's validity is based on three feasibility aspects: material, language, and media, which were validated by experts in geometry and pedagogy, psycholinguistics, and learning technology. The following provides a detailed explanation of each aspect.

First, the material feasibility aspect of this application was rated as very valid based on the alignment of the material with the Basic Competencies and Competency Achievement Indicators. This alignment is crucial to ensure that the presented material supports the achievement of learning objectives. For example, one of the Competency Achievement Indicators states that students should be able to illustrate the reflection of an object on a specific line. In this case, this application provides tools for drawing objects and lines, as well as features to reflect and display the resulting image. Therefore, material feasibility must include its alignment with the curriculum (Adamich, 2010; Krajcik et al., 2007).

Additionally, this application is considered feasible in the material aspect due to integrating constructivism principles, which enable students to construct their knowledge through active interaction with the material. This is consistent with Park's view that pedagogical approaches support the successful development of mobile applications (Park, 2011). Pedagogical approaches are strategies to enhance student engagement (Asif et al., 2021; Harms et al., 2017), facilitate conceptual and procedural understanding (Ross & Willson, 2012), and promote meaningful learning (Nel, 2017). For example, the application can provide interactive features that encourage students to simulate Geometric Transformation directly. Through these simulations, students learn theoretically and gain practical experience to reinforce their understanding.

Furthermore, mobile applications should integrate effective learning strategies, such as scaffolding (Grévisse et al., 2019; Jeng et al., 2010; Yin et al., 2013), which helps students build their knowledge gradually. Material should be presented in a structured and logical manner, from introducing basic concepts to more complex applications (Akugizibwe & Ahn, 2019). In this application, there are explanations of each type of transformation (translation, reflection, rotation, and dilation) with concrete examples of practical applications in everyday life. This assists students in understanding the topic procedurally and conceptually. Experts also agree that this application can explain complex concepts in an easily understandable way for students. According to Mbogo et al. (2013), scaffolding in mobile application development can take the form of step-by-step instructions, instant feedback, and exercises tailored to students' level of understanding. Somerton's study (2022) indicates that applications implementing scaffolding strategies can increase student engagement and motivation in learning.

Secondly, the language feasibility aspect of this application was rated as good based on the clarity of instructions and consistency in terminology. Experts suggested clarifying some instructions to avoid ambiguity and improving phrase segmentation for better meaning. This is consistent with the findings of Otten et al. (2017), who discuss the importance of precise language in mathematics learning. In addition, the findings of Riccomini et al. (2015) discussed that clear and concise instructions can enhance students' mathematical understanding. Furthermore, consistent terminology in learning applications is crucial to prevent student confusion during the learning process (Hughes et al., 2016). Therefore, using mathematically correct language that is appropriate for the grade level can help students learn mathematics effectively (Hughes et al., 2016; Townsend et al., 2012).

Thirdly, the media feasibility aspect of this application was rated as good based on visual display, user interface, and application navigation. This is consistent with the view of Christopoulos et al. (2018), who emphasize that a simple, intuitive, and consistent interface design can enhance student engagement in the learning process. This application employs a responsive design that adjusts the layout to the device's screen size. Interactive buttons are designed with sufficiently large sizes and precise color contrasts to ensure ease of use for students with varying levels of motor and visual abilities. Ayada and Hammad's study (2023) has shown that applications with an easily understandable interface, straightforward navigation, and structured layout can increase student satisfaction and encourage student motivation in mathematics learning. Moreover, according to Lin (2013), media feasibility not only prioritizes aesthetics but also function, which applies design principles that support accessibility and ease of navigation. Therefore, media feasibility serves as a bridge between material and students, ultimately supporting educational goals in enhancing their understanding and abilities (Ivers & Barron, 2010).

Practicality of the Developed Mobile Application

Empirically, the developed application was tested practical based on several main aspects, namely ease of use, clarity of instructions, efficiency, relevance of mobile application features to the material, flexibility of use, attractive and focus-supporting design, support for various student ability levels, and minimal technical disruptions. The findings of this study align with several previous studies. Herbert et al. (2018) showed that students tend to prefer applications with intuitive interfaces and simple navigation because this allows them to focus on learning without being distracted by technical problems. In addition, Wang et al. (2009) stated that applications that are responsive in providing feedback on learning activities have been shown to maintain student motivation during the learning process. The importance of minimizing technical disruptions is also a major concern. Technical disruptions can cause frustration and decreased student motivation, so application developers need to ensure the stability and accessibility of applications on various types of devices, including older or low-spec devices (Florenthal, 2018).

Effectiveness of the Developed Mobile Application

The results of the effectiveness test indicate that using a mobile application on the topic of geometric transformation was effective for achieving students' CT skills. This is consistent with studies showing the effectiveness of mobile applications in improving students' problem-solving skills (Malik et al., 2019; Şanal & Elmali, 2023). The effectiveness of the mobile application is supported by an interactive and engaging learning environment (Yusoff & Dahlan, 2013), immediate feedback and assessment (Zhang et al., 2015), portability and accessibility (Borba et al., 2016), visualization and interactive features (Shurygin et al., 2024), collaborative learning (Bringula & Atienza, 2022), and gamification (Ebner, 2015).

The developed application provides interactive features and simulations that help students understand complex concepts more easily (Shurygin et al., 2024; Zhang et al., 2015). Features such as practice questions with answer hints, material explanation videos, and example problems support students in performing problem decomposition, pattern recognition, algorithm design, and solution evaluation. In the mobile application, students are given geometric transformation problems and guided to solve them in simpler steps. For example, students are asked to perform a transformation on a quadrilateral by first rotating the shape at a specific angle and center point before moving it to another point. This process helps students understand the logical steps in solving geometric transformation problems in a structured manner.

In addition, students also recognize patterns of change that occur when geometric shapes are rotated, reflected, or translated. By observing how the same shape changes position and orientation repeatedly, students can develop their analytical skills to find patterns. Before this activity, they were asked to predict the results of certain transformations (in determining geometric transformation formulas).

Subsequently, students apply the concept of geometric transformation to the algorithms they create, and the application provides direct feedback on the results they achieve. In the practice question feature, if students make mistakes in calculating the transformation results, the application will provide instructions that guide them to reevaluate their process and analyze their mistakes. This learning activity educates students about the importance of good algorithmic thinking, evaluation, and reflection in learning mathematics.

Empirically, studies concerning the development of mobile applications in mathematics learning have been extensively conducted by numerous researchers in the past decade. However, some of these studies tend to limit themselves to using interactive visualization and accessibility features, essentially just transferring materials from printed books into a digital format. This approach, while enhancing portability, often fails to capitalize on the full potential of mobile applications in constructing student knowledge. In contrast, mobile applications possess the capacity to transcend static visualizations and simple accessibility by offering dynamic interactive simulations. The findings of this research reinforce the notion that interactive simulations are a key element capable of constructing student understanding of geometric transformation while also facilitating the achievement of their CT skills. The significance of these findings lies in the demonstration that mobile applications can be designed to create an active and exploratory learning environment where students not only consume information but also engage in the processes of discovery and problem-solving.

This study has several limitations that should be considered. First, it involved only a single group of students without a control group. This design introduces potential bias in assessing the effectiveness of the application, as changes in students' CT skills cannot be directly compared to a group not using the application. Therefore, future research is recommended to employ an experimental design with control groups to obtain a more valid and comprehensive evaluation of the application's effectiveness. Second, the sample size was relatively small, consisting of 51 students from two schools. This limited sample size restricts the generalizability of the findings. To enhance external validity, subsequent studies should involve larger and more diverse samples from multiple schools. Third, this study focused solely on geometric transformation material. Future research could expand the scope to other mathematical topics, such as general geometry or arithmetic, to explore the application's effectiveness in a broader mathematics learning context.

4. CONCLUSION

Based on the results and discussions of this study, it can be concluded that: (1) the process of designing a mobile application to achieve middle school students' CT skills through geometric transformation learning involved needs analysis, learning material and curriculum analysis, and application design that integrates interactive simulations and features supporting active knowledge construction; (2) the developed mobile application was proven valid based on aspects of material, language, and media feasibility; practical based on student response questionnaire results; and effective in achieving middle school students' CT skills, with the average student data-post scores exceeding the minimum passing grade.

The findings of this study have important implications for the future development of mathematics learning applications. First, this research highlights the need to shift the paradigm from applications focusing solely on visualization and accessibility to those that integrate interactive simulations and features that support active knowledge construction. Second, the study emphasizes the importance of application designs that actively engage students in the learning process, thereby providing meaningful learning experiences, strengthening students' understanding of geometric transformations, and achieving CT skills in middle school students.

Overall, this study contributes to educational theory and practice by demonstrating how mobile applications can achieve middle school students' CT skills through learning geometric transformations. Computational thinking is one of the higher-order thinking skills that opens opportunities for students to face future professional challenges and demands. Therefore, teachers and curriculum designers are encouraged to collaborate in creating more meaningful learning experiences through the utilization of mobile technology.

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Declarations

Author Contribution	: FN: Conceptualization, Investigation, Methodology, Software, Visualization, and Writing - Original Draft; YSK: Formal analysis, Supervision, Validation, and Writing – Review & Editing; DJ: Formal analysis, Supervision, and Writing – Review & Editing.
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