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Empowering Communities Through GeoGebra: A Training Program on Visualization Technology for Transformation Geometry

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Abstract The integration of technology in mathematics education has garnered increasing attention for its potential to enhance students' understanding of abstract concepts. This study examined the implementation of a GeoGebra-based training program for pre-service mathematics teachers at Universitas Singaperbangsa Karawang (UNSIKA), focusing on improving their visualization skills in transformation geometry. The training employed a project-based learning approach, incorporating online instruction, group projects, and collaborative discussions. Results indicated that GeoGebra effectively strengthened participants' conceptual grasp of geometric transformations, as evidenced by high project completion rates and positive survey feedback. Recorded instructional videos significantly supported self-paced learning, with 84.4% of participants utilizing these resources for project completion. However, challenges in comprehending coordinate transformations suggested a need for further guidance and targeted exercises. The study underscored GeoGebra's efficacy in advancing mathematical visualization skills and advocated for its wider adoption in mathematics teacher education. Future research should investigate extended training durations and adaptive learning strategies to address conceptual difficulties more thoroughly.

1. INTRODUCTION

The teaching of geometric transformations represents a fundamental component of mathematics education, requiring robust visualization skills to foster deep conceptual understanding. Visualization enables students to mentally manipulate geometric objects, facilitating clearer and more systematic comprehension of transformation principles (Octaviani et al., 2021). However, many students encounter difficulties when solving geometric transformation problems due to insufficient mastery of foundational concepts (Maulani & Zanthy, 2020). A solid conceptual foundation is critical, as it enhances students' ability to solve diverse mathematical problems effectively (Salma & Sumartini, 2022). Research has further confirmed that visualization-based learning strategies significantly strengthen students' grasp of geometric transformations, leading to improved learning outcomes (Asare & Atteh, 2022).

To mitigate these challenges, technology has emerged as a pivotal tool in supporting mathematics education, particularly in geometric transformations. GeoGebra, an interactive visualization software, has demonstrated substantial benefits in enhancing students' and pre-service teachers' understanding of geometric concepts (Ziatdinov & Valles, 2022). By leveraging GeoGebra, learners can dynamically visualize transformations, deepening their conceptual knowledge while improving learning efficiency (Afhami, 2022). Empirical studies reveal marked improvements in student performance following the

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integration of GeoGebra (Maf'ulah et al., 2021). Beyond academic gains, GeoGebra fosters engagement by prioritizing conceptual understanding over memorization (Mthethwa et al., 2020). Thus, incorporating GeoGebra into transformation geometry instruction offers an effective strategy to render abstract concepts more tangible and applicable.

Pre-service mathematics teachers occupy a strategic position as future educators tasked with advancing mathematics education. In Indonesia, the need for highly competent teachers is urgent, given the persistent challenges in mathematical literacy. The 2022 PISA results highlighted Indonesia's lowest mathematics literacy score since 2006 (Atikah et al., 2024), continuing a downward trend observed since PISA 2000 (Putrawangsa & Hasanah, 2022). Addressing this issue necessitates equipping pre-service teachers with the expertise to elevate future students' mathematical proficiency.

Against this backdrop, the authors implemented a training program for undergraduate mathematics education students at Universitas Singaperbangsa Karawang (UNSIKA), a public institution committed to developing professional educators in West Java. This initiative aimed to enhance pre-service teachers' technological competencies, particularly in utilizing GeoGebra as an instructional tool. Participants were trained not only in GeoGebra's functionalities but also in its effective classroom integration. The program sought to cultivate innovative educators capable of improving conceptual understanding and advancing mathematical literacy. Furthermore, this training represents a foundational effort toward strengthening Indonesia's mathematics education system in response to contemporary educational demands.

2. METHOD

The GeoGebra Training for Geometric Visualization was implemented over one week (November 26–December 3, 2024) at Universitas Singaperbangsa Karawang, involving 32 mathematics education students. The program adopted a project-based learning framework to develop hands-on GeoGebra skills, stimulate inquiry, and promote creative application of geometric transformation concepts (Z. et al., 2024). The training comprised three sequential phases:

2.1 Online class

This Conducted via Zoom on November 26, 2024 (40-minute session), this phase introduced four geometric transformations (reflection, rotation, translation, dilation) with live GeoGebra demonstrations. Participants were then organized into eight groups (four members each), each assigned a specific transformation project. The session was recorded and made available for asynchronous review.

2.2 Project

From November 26 to December 2, 2024, groups collaborated to complete their assigned transformations using GeoGebra. The instructional recording was hosted on YouTube as a reference resource. Final project reports (Microsoft Word format) were submitted via Google Drive by December 2, 2024.

2.3 Project discussion

The final stage of the training was conducted on December 3, 2024. During this session, participants discussed their completed projects while receiving constructive feedback and suggestions from the trainer regarding their work. At the session's conclusion, participants completed a Google Form questionnaire to evaluate both their project experience and the training's effectiveness.

To facilitate successful implementation, participants prepared necessary tools and materials in advance. This included laptops with installed Zoom software for the online class and GeoGebra application for project execution. The training approach specifically aimed to enhance students' digital technology skills for geometry instruction while deepening their understanding of geometric transformation concepts through interactive visualization.

The study employed a two-stage analysis. First, project outcomes underwent qualitative evaluation examining the accuracy and completeness of each group's work. This assessment focused on proper application of transformation concepts and appropriate GeoGebra usage in visual representation construction. These observations helped identify common errors and areas requiring improvement. Second, participant perceptions of the training process were collected via questionnaire, which addressed several key aspects: perceived difficulty levels, utilization of learning resources such as video recordings, and preferences for individual versus group project completion. Descriptive analysis of these responses revealed important trends and insights from participant experiences.

3. RESULT AND DISCUSSION

3.1 Online class

The online class was successfully conducted via the Zoom platform with all 32 students in attendance for the 40-minute session. During the session, the instructor provided a live demonstration using GeoGebra software to illustrate four essential geometric transformation techniques: reflection, rotation, translation, and dilation. To ensure participants could revisit the material as needed, the entire demonstration was professionally recorded and subsequently uploaded to a dedicated YouTube channel. Figure 1 provides visual documentation of this online class session, showing the instructor's presentation and the interactive elements of the demonstration. The session's structure allowed for real-time observation of each transformation type while creating a permanent reference resource that participants could access during their subsequent project work. This approach proved particularly effective as evidenced by the high percentage of participants who utilized the recorded material to support their independent learning and project completion.

The demonstration began with the visualization of the reflection concept. A triangle ABC, initially positioned in the second quadrant, was reflected across various axes and lines, including: (a) the X – axis, (b) the Y – axis, (c) the line $y = x$, (d) the line $y = -x$, (e) the origin (0,0), (f) the vertical line $x = -2$, and (g) the horizontal line $y = 1$. An example of the demonstration results for the reflection concept is presented in Figure 2.

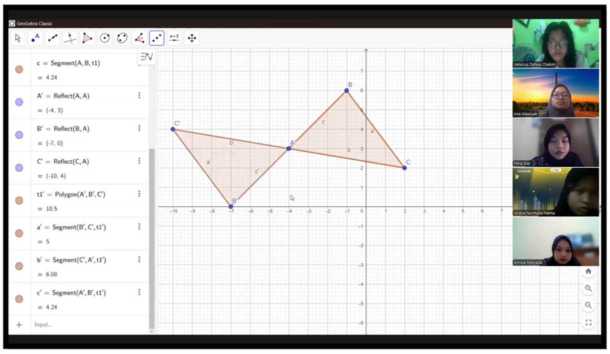

Figure 1 . Overview of the online class

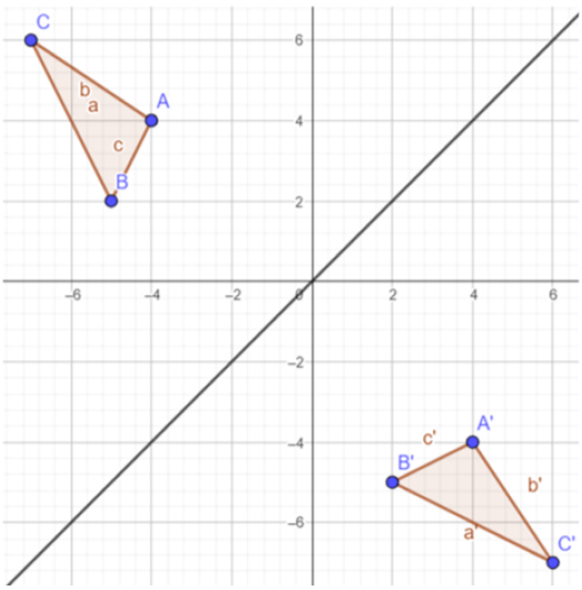

Figure 2 . Reflection of triangle *ABC* across the line $y = x$

The demonstration continued with the visualization of the rotation concept. The rotation was performed on triangle ABC with respect to two different centers. First, triangle ABC was rotated 90° clockwise about the origin (0.0). The demonstration then proceeded with a second rotation, where triangle ABC was rotated 60° counterclockwise about a different center, specifically (0.3). An example of the demonstration results for the rotation concept is presented in Figure 3.

The demonstration process continued with the concept of translation. Initially, a triangle ABC was constructed along with two translation vectors, $\overrightarrow{DE}$ and $\overrightarrow{FG}$. The visualization then illustrated the translation of triangle ABC using both vectors. At this stage, $\overrightarrow{DE} = \overrightarrow{FG}$ was intentionally set to further demonstrate to participants that a shape translated by the same vector will produce an identical image. An example of the demonstration results for the translation concept is presented in Figure 4.

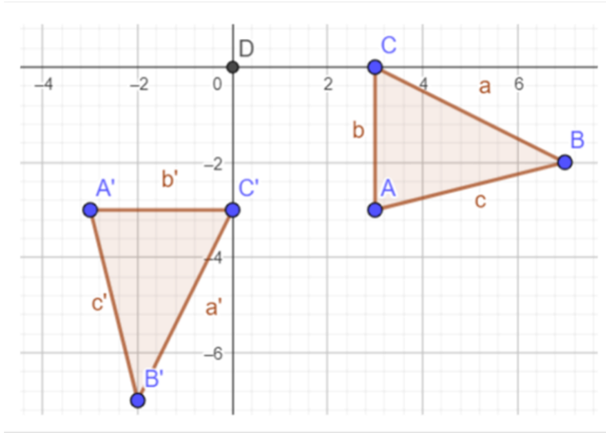

Figure 3 . Rotation of triangle *ABC* about the point (0,0) by 90° clockwise

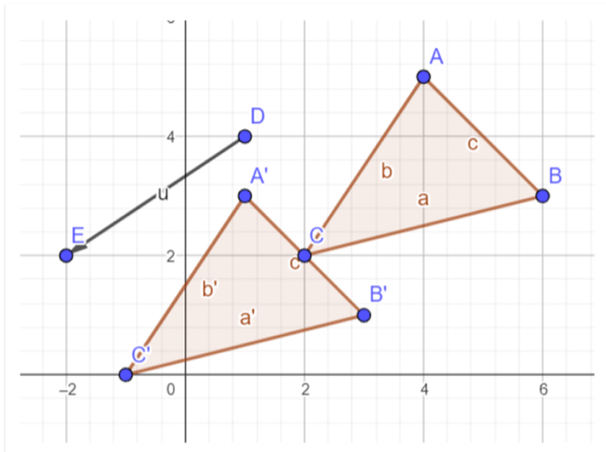

Figure 4 . Translation of triangle *ABC* by vector $\overrightarrow{DE}$

The next demonstration focused on the visualization of the dilation concept. This was the final part of the demonstration conducted in the online class, where a triangle ABC was dilated using two different centers. The first center was the origin (0.0), while the second was a non-origin point, specifically (3.4). In dilation, various conditions determine whether the image enlarges, shrinks, remains the same size, or changes orientation. These conditions were demonstrated by selecting different scale factors k. In this session, a scale factor $k > 1$ was used to enlarge the triangle while maintaining its original orientation with respect to the dilation center. The case $k = 1$ was shown to illustrate no change in size or orientation. The condition $0 < k < 1$ was demonstrated to produce a reduced image with the same orientation. Meanwhile, for transformations resulting in a reversed orientation, the scale factor $-1 < k < 0$ was used to shrink the triangle, $k = -1$ to maintain the original size but with reversed orientation, and $k < -1$ to enlarge the image while inverting its orientation. An example of the demonstration results for the dilation concept is presented in Figure 5.

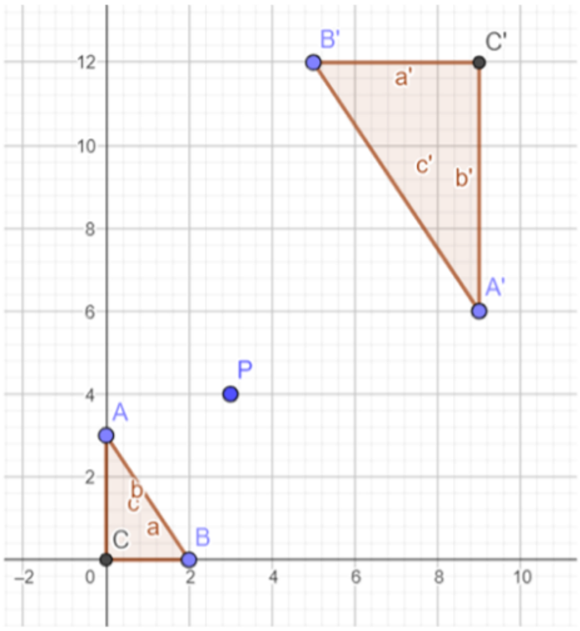

Figure 5 . Dilation of triangle *ABC* with center P and scale factor $k = -2$

3.2 Project

At this stage, participants were divided into eight groups, with each group consisting of four members. They were assigned a group project to be completed over one week. The project covered four aspects of geometric transformations: Project 1 for Reflection, Project 2 for Rotation, Project 3 for Translation, and Project 4 for Dilation. Each project was designed in two formats: (a) The first type was a simple project aimed at developing participants' visualization skills, following the demonstrations conducted during the online class session; (b) The second type was an exploratory project, intended to enhance participants' problem-solving skills in geometric transformations. The simple projects required participants to replicate given geometric transformations using digital tools, ensuring accuracy in their constructions. Meanwhile, the exploratory projects encouraged participants to formulate conjectures based on observed transformation properties and justify their reasoning using mathematical principles. The data collected from both project types were analysed to assess the effectiveness of each approach in improving spatial reasoning and conceptual understanding. The following are examples of each type of project.

3.2.1 An example of a simple project

1. Given a polygon *ABCD* with vertices $A(-2,2)$, $B(2,2)$, $C(2,4)$, and $D(-2,4)$, visualize the following using GeoGebra:

    a. The polygon *ABCD*

    b. The dilation of polygon *ABCD* with center at (0,0) and scale factor $k = -2$, then determine the coordinates of the transformed vertices A', B', C', and D'.

    c. The dilation of polygon *ABCD* with center at (0,2) and scale factor $k = \frac{1}{2}$, then determine the coordinates of the transformed vertices A', B', C', and D'.

2. Determine the area of polygon *ABCD* before and after the dilations in Question 1.

3.2.2 An example of an exploration project

Construct a hexagon in the second quadrant, then determine a centre point and a scale factor k that will transform the hexagon to the fourth quadrant with a threefold enlargement

3.3 Project discussion

At this stage, a discussion process was conducted regarding the project outcomes completed by the participants. Based on the project results, six out of eight groups successfully completed all tasks correctly. However, two groups had specific notes for discussion.

Following the discussions and revisions based on the initial findings in Table 1, a comprehensive questionnaire was administered to evaluate participant responses. The survey results demonstrated that 84.4% of participants reported substantial support in learning to construct geometric transformations through GeoGebra. A statistical analysis of the questionnaire data revealed key trends in participants' perceptions of the learning experience. The findings highlighted that the primary challenges centered

Table 1 . Note and evaluation

No.	Note	Evaluation
1	Create a triangle in the third quadrant, then select a mirror to obtain its reflection in the fourth quadrant. Draw the transformation using GeoGebra.	The reflected image was mistakenly placed in the third quadrant, while the original triangle was in the fourth quadrant.
2	Create a circle in the first quadrant, then determine a point and an angle to move the circle to the fourth quadrant.	A point and an angle should have been chosen for the rotation, but one group mistakenly used a vector to transform the circle through translation.
3	Create a circle in the second quadrant, then determine a centre point and a scaling factor k to enlarge the circle three times its original size and move it to the fourth quadrant.	Some groups did not fully transform the circle into the fourth quadrant, leaving parts of it still in the first, second, and third quadrants. Additionally, another group applied two consecutive transformations to move the circle from the second quadrant.

around comprehending complex transformations and accurately implementing them in project tasks. Figure 6 presents the detailed breakdown of participant-reported difficulties encountered during project completion, providing valuable insights into specific areas requiring additional instructional focus. These results informed subsequent refinements to the training methodology to better address conceptual hurdles in transformation geometry.

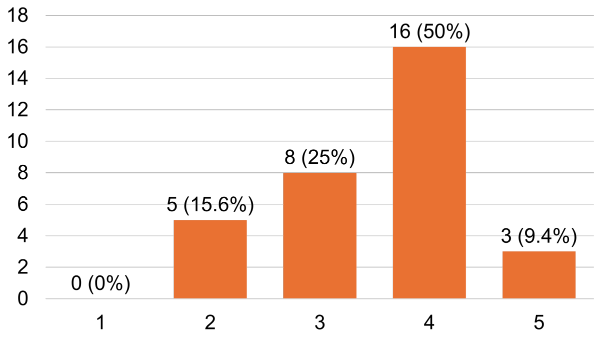

Figure 6 . Project difficulty level

Based on the bar chart, it is evident that participants perceived the difficulty level of the project to be 4 out of 5. This indicates that while the project presented significant challenges, it remained manageable for most participants. The high difficulty rating suggests that the tasks required substantial cognitive effort, likely due to the need for precise geometric visualization and the application of transformation concepts using GeoGebra. These findings highlight the importance of providing adequate instructional support and structured guidance to ensure that participants can effectively develop their mathematical visualization skills.

Meanwhile, based on the process of completing the project, it was found that 84.4% of participants reviewed the recorded videos uploaded on YouTube to assist them in completing the project. Additionally, 81.3% of participants sought supplementary learning resources from YouTube to support their project work. The process of project completion is presented in Figure 7.

Based on the pie chart, 43.8% of participants preferred to complete the project independently, indicating a strong inclination toward individual problem-solving and self-reliance. Meanwhile, 18.8% preferred working with their team, highlighting a reliance on collaboration and group discussions to accomplish tasks. Additionally, 37.5% demonstrated flexibility in their working approach, balancing independent work and teamwork depending on the project's demands. These findings suggest diverse work style preferences and underscore the importance of flexible learning environments that accommodate both independent and collaborative strategies.

The findings of this study underscore the effectiveness of integrating GeoGebra into the teaching and learning of geometric transformations. The online class provided students with opportunities to develop foundational visualization skills, which were further reinforced through hands-on, project-based learning. The results indicate that GeoGebra facilitated a deeper conceptual understanding of transformation geometry, as reflected in the high project success rate—six out of eight groups completed their tasks without major errors. These outcomes are consistent with previous research demonstrating that visualization-based learning enhances students' comprehension of abstract mathematical concepts (Asare & Atteh, 2022; Mthethwa et al., 2020).

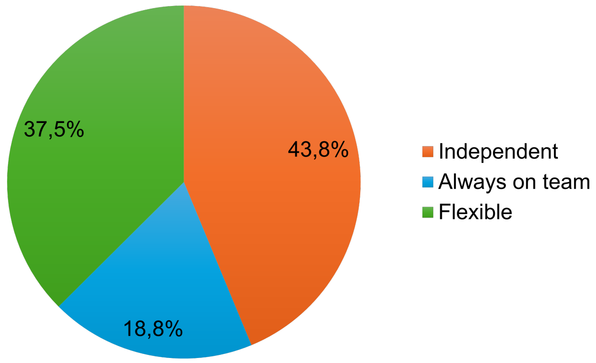

Figure 7 . Process of project completion

Moreover, the structured nature of the training, which began with an online introduction, followed by a project phase, and concluding with a discussion session, provided a progressive learning experience. The availability of recorded materials on YouTube was also instrumental; 84.4% of participants reported revisiting the videos to support their project completion. This aligns with findings by Ziatdinov & Valles (2022), who emphasized the value of digital learning tools in promoting self-paced and independent learning.

However, the challenges faced by some participants indicate that certain aspects of transformation geometry require additional instructional support. Errors related to incorrect quadrant placements in reflections and rotations highlight the need for more explicit guidance in manipulating coordinate systems. These findings reinforce Maulani & Zanthy (2020) argument that students often struggle with geometric transformations due to insufficient conceptual mastery. Addressing these challenges through more interactive guidance and targeted problem-solving activities could further enhance student learning outcomes.

In addition to its functional role in completing assigned tasks, GeoGebra served as a powerful cognitive tool that supported participants in visualizing abstract mathematical concepts. Its dynamic features enabled real-time manipulation of geometric objects, encouraging active exploration and immediate feedback. This approach aligns with constructivist principles, where learners build understanding through hands-on interaction and reflection. Participants were able to test conjectures, observe the effects of various transformations, and correct misconceptions, either independently or collaboratively, within a highly visual and interactive environment.

Furthermore, GeoGebra facilitated a shift from procedural to conceptual learning. Rather than merely applying transformation rules, students engaged in deeper reasoning about the underlying properties of geometric figures. For instance, when adjusting scale factors or centers of rotation, participants began to recognize invariant properties such as shape congruence in rotations or proportionality in dilations. This process enhanced their mathematical reasoning and spatial awareness, and these are skills that are often difficult to cultivate through static, paper-based instruction alone.

GeoGebra also played a critical role in increasing student motivation and engagement. Its intuitive interface and instant visual feedback lowered cognitive barriers for students who might otherwise struggle with traditional geometry tasks. The ability to experiment freely and receive immediate results was frequently mentioned in informal participant reflections and group discussions. These observations align with earlier findings by Mthethwa et al. (2020), which highlight GeoGebra's capacity to promote curiosity and reduce anxiety in mathematics learning.

Finally, the use of GeoGebra supported the broader goal of preparing pre-service teachers for 21^{st}-century classrooms. Participants not only learned how to use the software but also gained insight into integrating technology meaningfully into pedagogical practice. By designing and completing both structured and exploratory projects, they experienced firsthand how visualization tools can support student learning outcomes, thereby developing both content knowledge and pedagogical expertise.

4. CONCLUSION

This study demonstrates the positive impact of GeoGebra-based training on pre-service mathematics teachers' ability to visualize and apply geometric transformations. The structured training program, incorporating online instruction, project-based learning, and collaborative discussions, successfully enhanced students' conceptual understanding and technological proficiency. The high engagement rate and significant use of supplementary materials highlight the effectiveness of integrating technology into mathematics education.

However, the results also revealed several learning challenges, particularly related to the correct placement of transformations within the coordinate plane and the application of transformation rules. These issues suggest a need for more explicit guidance and practice in key areas. Based on these findings, several recommendations can be made for future training programs. First, targeted exercises on coordinate system manipulation should be included to help students overcome common spatial reasoning errors. Second, extending the training duration would allow more time for deeper exploration and practice, especially for complex transformation types. Third, the incorporation of formative assessments throughout the training process would help identify conceptual misunderstandings early and allow for timely intervention. Additionally, encouraging reflective practices such as requiring participants to explain their reasoning can strengthen their metacognitive skills. Training should also include strategies for integrating GeoGebra into actual classroom teaching, helping participants develop not only content knowledge but also pedagogical skills. Finally, peer feedback sessions can be introduced to promote collaborative learning and improve communication among participants.

Overall, this research contributes to the ongoing discourse on technology-enhanced mathematics education, emphasizing the crucial role of digital tools like GeoGebra in fostering deeper mathematical understanding. Given the challenges faced by mathematics education in Indonesia, particularly in relation to students' low mathematical literacy levels, equipping future educators with robust technological skills is a strategic step toward improving learning experiences and outcomes in mathematics classrooms.

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CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest related to this study.

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