Use of GeoGebra in Teaching and Learning Geometric Transformation in School Mathematics

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Abstract—The use of GeoGebra in teaching geometric transformations was investigated in this study. GeoGebra is a math software available in over 100 plus languages, both online and offline. GeoGebra is a useful application to improve and enrich mathematics teaching and learning by allowing students to visualize mathematical concepts, which is extremely useful for mathematical experiments and discoveries at all educational levels, from elementary school to university. The theoretical referents used in this article are cognitive learning theory and Vygotsky's social learning theory. Twenty students (twelve boys and eight girls) in grade IX from a private school in Kathmandu Valley, Nepal, were taught mathematics using a variety of specific instances of transformation highlighted in this study, including reflection, rotation, translation, and dilation. This research used a qualitative research method called a teaching experiment to examine the use of GeoGebra in eleven episodes. Students were aided in visualizing abstract concepts of change by using relevant images, photos, and animations of GeoGebra-created objects. The findings of a classroom experiment are GeoGebra is an easy-to-use application, GeoGebra allows for discovery learning, GeoGebra encourages collaborative learning, and GeoGebra to visualize geometric transformations. Likewise, GeoGebra aids in the teaching and comprehension of abstract transformation concepts. These findings show how students can develop into active knowledge builders when GeoGebra is used in mathematics classes. They also communicate with one another, keep track of the change process, and respect their instructors' authority in such classes. It is an important instructional tool that supports the educational system's transition from a teacher-centered to a learner-centered approach by complementing the traditional lecture method of teaching mathematics.

Keywords—GeoGebra, transformation, mathematical experiment, episodes, authority, approach

1 Introduction

Technology is an extremely effective tool for involving students in mathematics instruction. Without a doubt, technology has evolved into one of the most effective tools for learning and teaching mathematics. In this vein, new technology tools such as GeoGebra, Google Sketch Up, and Sketch Pad, among others, have proven to be more effective at improving and enriching mathematics teaching and learning by allowing students to visualize mathematical concepts. For many years, the strategic use of technology in mathematics teaching and learning has included students and teachers using digital and physical resources in carefully constructed situations [18], [19]. In the case of Nepal, Nepali mathematics teachers are missing these opportunities to integrate GeoGebra in this digital era with the advancement in technology. This research shall be the one that could contribute to integrating GeoGebra application in teaching geometric transformation. Likewise, "GeoGebra, a mathematics software, combines interactive geometry, algebra, statistics, and calculus to create the most comprehensive application for producing and explaining mathematical ideas for students from elementary school to university level education." [11, p. 323]. Markus developed GeoGebra application as part of his master's thesis in mathematics education and computer science at Salzburg University in Austria (2001/2002), which was a combination of mathematics education and computer science.

Similarly, twenty-first-century students are familiar with the graphical culture of mathematics and other subjects due to their constant access to various social media. This means that the traditional lecture-based method of teaching mathematics continues to predominate in Nepali schools, despite the country's growing graphical culture of mathematics teaching and learning. The lack of a correct representation, followed by static mathematical graphs in the traditional approach to teaching mathematics, i.e., drawing it on a piece of paper, could be the most significant barrier to learning mathematics. Static objects may prevent students from generalizing concepts [6]. Guided by the theoretical framework of cognitive learning theory, and Vygotsky's social learning theory, the goal of this study was to explore if GeoGebra's dynamic geometric software could be used to teach and learn geometric transformations as a powerful tool for teaching and learning mathematics [11]. The purpose of this study is to see if using GeoGebra aids students in understanding geometric transformation concepts. In this line, this research aimed to see how the dynamic geometric software GeoGebra could be used to teach and learn geometric transformations. The question—how can students use GeoGebra to improve their understanding of geometric transformations?—serves as a guiding research question for the study. This research is not too implacable for everyone but helpful for readers, beginning teachers, novice teacher trainers, and educational researchers who are interested in integrating the GeoGebra in teaching and learning mathematics, primarily geometric transformation. With this introduction, in this article, we present the literature review, theoretical referents, methodology, discussion of findings, drawn conclusions, and possible implications in the next sections.

2 Literature review

Technology plays an essential supporting role in mathematics instruction. When technology is used effectively, it has the potential to accelerate and improve student learning. Teachers and students can conduct research on mathematical concepts with the appropriate use of technology. As a result, it profoundly affects how mathematics is taught, and students learn [3]. However, [20] examined the impact of computers and tablets on the development of math skills in pre-kindergarten. The results indicated that their math skills improved when children were taught math using tablets rather than computers. Also, another study examined the effect of computers and tablets on young children's understanding of number concepts. When used in combination with age-appropriate software, computers and tablets can significantly improve young children's ability to comprehend numbers [21]. Despite the significant impact of tablets, GeoGebra is a valuable pedagogical tool for visualizing a wide variety of mathematical formulae in both algebraic and geometric representations [17].

Additionally, incorporating these technologies into mathematics education has the potential to increase the effectiveness of teaching and learning activities while also saving time. It has the potential to be a beneficial tool in increasing the educational system's effectiveness. Correspondingly, incorporating ICTs into mathematics classrooms may aid instructors in creating a dynamic learning environment and motivating students to grasp mathematics. Rather than that, using information and communication technologies, it is possible to illustrate movement by simply dragging 'free' objects across the drawing's plane. Students' understanding can effect change through ICTs by implementing a method or manipulating free items, and they can understand how dependent items are impacted. Following that, students will be able to solve problems through the investigation of mathematical relations. While sketches on paper or on a whiteboard can enable in conceptualization, these static representations frequently fall short of expressing mathematical principles. "When the function f(x)=mx + c is graphed, students can investigate the relationship between the gradient (slope) and y-intercept of the line (where 'm' represents the slope of a line and 'c' represents the y-intercept)." [23, p. 12]. For instance, in mathematics, numerous additional subjects can be viewed in the classroom through the use of the GeoGebra application on a computer or tablet.

Additionally, mathematics is applicable to a broad range of disciplines, including engineering, astronomy, finance, economics, and statistics. As a result, these concepts can be applied in the real world to support real-world data analysis. The above disciplines can be explored through the use of physical objects, such as real, virtual, and graphical objects. This method of incorporating actual objects into schooling has had a tremendous impact on psychology and education [5], [22]. The advantages of using authentic objects are that they provide context for learners to grasp real-world knowledge. Similarly, through the use of actual objects, learners can engage in debates and generate knowledge about abstract concepts [4]. GeoGebra, for example, is an ICT tool (or mathematical software) that facilitates the connection between the abstract concept of geometry transformation and physical objects through the use of a picture and its motion. Thus, when GeoGebra is used to teach similar subjects, it promotes the adoption of complementary software that enables students to visualize mathematics. Thus, GeoGebra may support the abstractification of mathematics. Without a doubt, GeoGebra can assist with visualization.

However, inadequate geometry comprehension leads to students becoming discouraged and performing poorly in geometry [15]. Additionally, certain factors have been identified as contributing to the difficulty of learning geometry: geometry language, visualizing ability, and insufficient tutor(s) teaching [15] and [11]. Taking this into account, [15] stated that specific spatial visualization had been associated with geometric achievement, as geometry is visually represented in the natural world. Geometry is the study of shape and space; it necessitates the development of visualization abilities, which many students lack [13]. As a result, studying geometry can be challenging, and many students struggle to grasp its principles, reasoning, and problem-solving abilities, even when incorporating ICT tools such as GeoGebra into Nepali mathematics education presents both changes and challenges [6].

3 Theoretical referents

Using the cognitive learning theory and Vygotsky's social learning theory, this article investigates the use of GeoGebra in the teaching and learning of mathematics at the secondary level.

3.1 Cognitive learning theory

Throughout a person's lifetime, the cognitive theory is concerned with the development of his or her mental processes. Generally writing, it can be defined as "the act or process of knowing" in a broad sense [2]. According to this viewpoint, a human learns when environmental information is converted into and stored in the human's memory. Information is acquired through experience or modifying previously acquired knowledge to adapt to a changing environment. This theory also focuses on the mind and attempts to demonstrate that knowledge is typically acquired, digested, stored, and remembered in the brain. So, according to cognitivism, knowledge can be gained through listening, observing, feeling, researching, and processing and retaining the information. A variety of software programs, such as GeoGebra, Google Sketch Up, and Sketch Pad, can be used to aid in cognitivist learning processes. GeoGebra is one of the software that is frequently used in the classroom to teach mathematics to demonstrate cognitive learning but not limited.

3.2 Vygotsky's social learning theory

[27] believed that the construction of meaning is assisted by the participation of others in the process. According to this theory, knowledge is created through social interaction. The use of a wide range of resources, including language, culture, everyday activities, tangible objects, interpersonal contact, and peer interaction, is envisioned as part of this concept of learning and development [12], [14]. By participating in additional discussions, dialogues, listening, speaking, and other activities in the classroom, students are encouraged to interact and discuss with one another and with the teacher. So, according to Vygotsky, social contact is necessary for cognitive development. Students can collaborate with their classmates and teachers to investigate ideas, beliefs, conceptions, and misunderstandings by utilizing cooperative, collaborative, and group research approaches. Further, [27] suggested that there is a dividing line between what a student can accomplish on his or her own and what he or she can accomplish with assistance in the zone of proximal development. Students can complete tasks that they would otherwise be unable to complete on their own with the assistance of other friends

and/or teachers in the classroom. During our experiment lessons, the use of GeoGebra provided them with the same assistance. Because students already had some prior knowledge, GeoGebra was able to assist them in scaffolding their geometric transformation understanding. Therefore, the first author conducted interviews with students to determine their current level of transformation knowledge and then set out to provide them with resources that would help them advance their understanding of the subject matter. The students got benefited from the use of pictorial illustrations, animations, and other appropriate illustrations. Similar to this, social constructivism played a role in the decision of the first author to offer collaborative research processes. The first author attempted to create an environment in which students would actively participate in discussions about the subject matter. In order to accomplish this, the first author has set aside four minutes each day for a discussion on the effectiveness of the previous session in terms of their understanding. The first author assigned students to solve specific problems in a similar manner to the one described during the experimental classes. They collaborated with one another to arrive at the correct response. Some of the participants' interactions with their peers led to the development of new information for some of the participants. The first author allowed students to use GeoGebra to investigate geometric transformation characteristics during the other days. Students assisted one another as they went about their assigned work. Students also helped each other out when they were playing games on the GeoGebra application. All of these social interactions aided students in learning new information, improving their understanding, and excelling in their skills to run the GeoGebra application.

4 Methodology

We used a teaching experiment approach to examine the effectiveness of GeoGebra in teaching geometric transformations in school mathematics [25]. We used cognitive learning theory, and Vygotsky's social learning theory as theoretical referents in our investigation. It was guided by the research question: "how can students use GeoGebra to improve their understanding of geometric transformations?" Teaching experimentation is a qualitative methodology that does not have the essence of generality in the general sense but has some form of generalizability and does not have to be repeated in a different environment. In order to conduct a critical examination of the emotions and actions displayed by participants in experiment classes, we used a teaching experiment technique. We chose teaching experiments over qualitative research methods because the technique was developed specifically for mathematics education. The goal of this technique was to gain a better understanding of how students learn. We had two weeks of experiment classes. We used GeoGebra to teach geometric transformations such as reflection, rotation, translation, and dilation in eleven episodes in experiment classrooms with the assistance of a witness researcher. We used GeoGebra to create relevant pictures, photographs, and animations of objects to help students visualize abstract transformation concepts. We chose twenty students (twelve boys and eight girls) in grade IX from a private school in Kathmandu Valley, Nepal, to study and serve as the research site. A teacher or educator can examine students' mathematics learning and reasoning personally as a researcher by employing the teaching experiment approach [25].

Furthermore, we can only conduct a teaching experiment with students if we are able to participate actively alongside them. Our research collected information from students through responsive and intuitive interactions. Because it is difficult to comprehend how children can acquire so much information in such a short period of time, we worked instinctively with the same students for two weeks. We set out to find out how children come to know about geometric transformations and how they learn about them. A teaching experiment is made up of a series of instructive sessions [26]. The authors divided the study period into eleven instructive events, each of which was discussed in detail. In addition, the authors included a witness-researcher in the study to document the anecdotal behavior of the research participants. The first author used GeoGebra to assist in teaching geometric transformation [24], [11] and the other authors involved in planning the lessons, analyzing the field notes, and drawing meanings out of the collected information and texts. It took significantly more time and effort than teaching [25].

As researchers and educators, we looked back on the data we had gathered. We were able to conduct a critical analysis of the teaching experiment techniques by observing the emotions and actions displayed by students who participated in the study. Then, while watching video recordings of the experiment classes, we observed the students' actions. Throughout the tasks, the participant's body language, facial expressions, and classroom behavior were all observed and recorded. In addition, we took notes on the information gleaned from the witness-researcher. In a similar vein, we taped and typed student interviews. Then, based on the findings of the investigation, we developed a theme using generic qualitative techniques such as quotes, categories, and themes. Following the evaluation and interpretation of the data, we conducted an analysis of the study's findings.

5 Discussion of the findings

This section presents the key findings investigation grounded on theoretical referents and methodological stances. Our interactions with participants and our retrospective examination of the records collected in the experiment classes yielded the following findings for discussion.

5.1 GeoGebra is a simple to use application

We discovered that our participants found the GeoGebra program to be straightforward to use during our research. Their faces lit up with excitement as they took in the GeoGebra screen and the tools necessary to operate it. When it came to using GeoGebra software, the majority of students had no problems during the research period. Even though we had to coach them at times, they handled GeoGebra like professionals for the most part. Individuals using GeoGebra and developing their own mathematical ideas gave us great pleasure to witness. Explaining the GeoGebra tools and their applications was straightforward for the first author who wrote about them.

Throughout the experimental classes, we provided participants with the opportunity to play GeoGebra games and puzzles. They were excited to discover that GeoGebra could also be used for gaming purposes. The students skillfully maneuvered the items in GeoGebra as they completed the challenge and participated in the game. This allowed us to judge how well-versed students are in today's technological advancements. Participants were asked whether they were confident in their ability to use GeoGebra during a discussion led by the first author, and the majority of them responded affirmatively. There was a strong sense of trust in the authors' voices throughout the classes. GeoGebra simplifies the process of learning geometric transformations for students. Furthermore, it enables students to investigate new mathematical topics even when a teacher is not present to supervise their work. Students benefit from it because it assists them in the development of complete procedures. They generate new transformation ideas and make connections between new information and what they already know. Its user-friendly interface enables students to investigate various aspects of geometric transformation on their own, with and without the support.

5.2 Deep learning via GeoGebra

We discovered that students were actively participating in classroom activities with a lot of enthusiasm. They communicated with the authors regularly throughout the classes and attempted to learn at their own pace. We discovered them captivated as they observed the first author incorporating technology into the classroom. It appeared that this was their first experience in a formal classroom setting. Students were at the heart of the first author's research classes, which contributed to the advancement of constructivism in learning [5]. In the majority of the lessons, we worked with a variety of geometrical objects. We created geometrical objects, experimented with object variables to see how they affected their attributes, and animated, reflected, and rotated them to see how they changed over time. After giving a brief demonstration, the first author then allowed students to construct geometrical structures on a GeoGebra worksheet. In GeoGebra, students could construct things, adjust object variables, reflect and rotate objects, and then track changes in the objects' locations and pictures. When GeoGebra was used, students were adequately engaged to complete the task. While one of the participants was occupied with running GeoGebra, the other participants talked about how to make proper use of the GeoGebra tools. They were offering assistance to one another. It infrequently happened in ordinary classrooms because the first author was the only one who shared his thoughts. As an alternative to having students simply observe a transformation demonstration, it was suggested that they view the transformed items and then plot them on graph paper, allowing them to actively participate in the activity rather than just passively observer. They were not afraid to communicate with the first author or to demonstrate their abilities throughout the experimental classes. They made mistakes, but it was through these mistakes that they were able to grow. The first author had no problem guiding them through the textbook problem.

They were motivated to take an active role in completing the assignment after noticing the change. Additionally, when we used GeoGebra software to design an item and then change it, students felt at ease, allowing them to investigate the relationship between object location and picture. The majority of the time, they came up with the connection (formula) between the location of an item and an image on their own, without assistance. They were compiling a large amount of information for later use. During experiment classes, students engaged with us more frequently than during regular sessions, indicating that they had progressed from passive receivers to active learners. The data we have collected during our research and our observations lead us to believe that GeoGebra assists students in actively deep learning geometric transformations.

5.3 GeoGebra enables discovery learning

We discovered that GeoGebra is useful in assisting students in discovering new ways of learning mathematics. When investigating mathematical topics, it can be very helpful. Students can create geometric figures on their own and experiment with the many features of the object by simply dragging the variables around the screen [1]. For the first author's experiment classes, we no longer represented the typical instructor who taught mathematics exclusively through the lecture approach, but rather we represented the typical student who learned mathematics through hands-on experiences. In order to gain a better understanding of mathematical concepts, we became acquainted with them. As a co-learner, the first author worked in collaboration with students. We observed that the children were actively involved in their learning. Over the course of the study period, the majority of students volunteered to use the GeoGebra software to investigate the properties of various geometrical objects. Students could be encouraged to investigate fundamental geometrical concepts using GeoGebra throughout in their schooling. Throughout the sessions, participants attempted to determine the relationship between an object's location and its changing appearance. Consequently, if students are given the opportunity to use GeoGebra, they have the potential to independently discover mathematical concepts. Having a sense of ownership over their work instills a sense of pride in them. We were able to create an environment conducive to independent learning thanks to GeoGebra's assistance as a teacher-researcher. As the first author, acted as a coach rather than as a conduit for the transmission of information. In a similar vein, through the exchange of information, students came up with a variety of transformational conceptions. GeoGebra makes a positive contribution to constructive learning when used in this manner. Finally, we discovered that GeoGebra facilitates discovery learning, which improves the overall quality of teaching and learning activities in the mathematics classroom but not limited.

5.4 Using GeoGebra to enhance understanding of geometric transformations

We revealed that some students were afraid of mathematic problems when we spoke with a few students before the experiment classes. In response to the first author's inquiry about their previous grade geometry lessons, one of the students stated that she used to grasp the information but was unable to retain it for a longer period of time due to her learning disability. She expressed dissatisfaction with her eighth-grade teacher for failing to demonstrate the process of reflection and rotation to her. It's possible that this was one of the factors contributing to her inability to comprehend the reflection and rotation processes.

On the other hand, participants seemed to enjoy studying geometric transformations throughout the course of the study, as we discovered. Because of their movements and facial expressions, it was clear that they had a better understanding of metamorphosis than they had in eighth grade. Our students' cheeks were lit up as the first author explained some complex mathematical topics in GeoGebra, which we all witnessed. On the first day of the class, one of the participants said to the first author, "*Sir, I believe that if I am taught in this manner, I will retain the mathematical concepts for a longer period of time.*" On several occasions during research classes, the first author invited a group of students to demonstrate how to use the GeoGebra program with the assistance of the other authors, which they gladly did. It instilled in them the sense of pride in knowing that they were the creators of their own work. They were thrilled to have the opportunity to work with the GeoGebra software. It aided them in better comprehending the concept of change. They were the ones who came up with the information. After episode two, we conducted a post-episode two interview with students and discovered that they were able to visualize the process of reflection and rotation with relative ease.

They stated that the visual representation of geometric transformations helped them better understand transformations in general. They were more engaged and active during experiment classes; according to one student, than they were during regular classes, he said. Other students expressed a preference for participation in the experiment classroom over participation in the regular classroom. According to the data collected, we can conclude that participants gained a better understanding of geometric transformations as a result of their participation in the GeoGebra simulation.

5.5 GeoGebra fosters collaborative learning

There was frequent communication between the researchers and the students in our observations. The classroom had a warm and inviting feel to it. Students helped one another while they were playing games and using the GeoGebra. Aside from that, they assisted each other in resolving puzzles in GeoGebra worksheets as well. When some participants walked to the front of the classroom to use GeoGebra to create and alter an item and made a mistake, other participants assisted their buddy in using GeoGebra to correct their mistake. While they were also completing classwork, they were able to assist one another in overcoming difficulties. Students were encouraged to approach the first author with any questions they had and to present their work to him. According to students who participated in an interview after each teaching session, the classroom was more engaging than a traditional classroom. Students worked together to complete learning tasks in the experiment classroom. Because students interacted and information was created in a social setting after reflecting their understanding to each other [28] the research courses were supported by Vygotsky's social learning theory. Following this conclusion, we concluded that using GeoGebra elevated (scaffolded) students from their current level of knowledge to a higher level of understanding.

5.6 GeoGebra for visualizing geometric transformations

As a result of his extensive research, the first author discovered that many students had difficulty comprehending certain mathematical concepts when they were questioned in large groups. Some of them were unable to fully understand mathematics due to their inability to see things clearly in their minds. According to our findings, GeoGebra can be used effectively to assist students in comprehending difficult mathematical concepts. When the first author moved materials during experiment classes to demonstrate the many concepts of geometrical objects, the students were taken shocked and surprised. When the first author demonstrated the reflection and rotation processes to them, they were overjoyed and elated, to say the least. It was a new and exciting experience for them to witness the reflection and rotation processes. Students were enthralled by the fact that objects moving in an unexpected manner during transformation. During a later stage of the research, when the first author discussed the relationship between the location of an object and a changed picture, the majority of participants believed that they could maintain the relationship for a longer period of time. They were all in agreement that it was due to the GeoGebra visualization that they had used. In support of [22] 's cognitive theory, which states that learners first develop concrete conceptualizations before progressing to abstractions. After lunch on the eighth day, we played a game in which players had to identify the object's axis of reflection in addition to the image in the GeoGebra worksheet. I encouraged everyone to participate in the activity. They made mistakes, but they also gained knowledge as a result of their experiences.

Following that, almost all of the participants were able to determine the correct reflection axis by themselves. Their ability to recognize the reflection axis, the object, and the image in the game was aided. Consequently, one could argue that the vast majority of participants in the iconic stage generated conceptions of change through the use of images, moving objects, and videogames, among other means. On the tenth day of class, one of the students reported that he was able to visualize the reflection and rotation processes and recall the rotation direction because he had practiced. He used to have a difficult time determining the direction of rotation in both positive and negative directions when he first started. He was able to overcome this obstacle after participating in the experimental class and receiving assistance from the teachers. While participating in the interview, one of the participants stated that she has demonstrated the ability to overcome transformative difficulties quickly. As she explains it, picturing assisted in achieving her goal because it allowed her to maintain the relationship between the thing and the picture even after a distance separated them. They agreed that GeoGebra enabled them to see motions such as reflection, rotation, translation, and dilation in 3-D space. This conclusion corroborated the cognitive learning hypothesis, which states that learning occurs through listening, seeing, and studying, followed by knowledge processing and retention after the learning experience. As a result, GeoGebra makes it easier to represent geometric changes in a mathematical model.

6 Conclusions

This study sought to determine whether GeoGebra could be used to teach geometric transformation. In collaboration with other authors, the first author used a teaching experiment technique to gain an understanding of students' mathematical understanding of geometry transformations using GeoGebra in this study. Similarly, the other authors collaborated to ascertain how students conceptualized geometric change [8], [9], [29]. The first author observed students' enthusiastic participation in experiment classrooms and their apparent eagerness to grasp change through the use of GeoGebra software throughout the investigation in the collaborative learning process [10]. To motivate students, [16] asserts that teachers must transition away from traditional lecture-based pedagogies and toward more contemporary activity-based, collaborative, and cooperative learning pedagogies. We discovered that incorporating GeoGebra benefited at least one (or more) of these contemporary pedagogies while also inspiring students to pursue mathematics. The learner's experiment demonstrates how using GeoGebra to teach and study geometric transformations can help students retain their knowledge. Additionally, students' classroom behavior and subsequent responses indicated that GeoGebra assists students in conceptualizing abstract mathematical concepts. Additionally, GeoGebra may assist students and teachers in making mathematics more enjoyable in the classroom through mutual understanding [7]. Additionally, this strategy can be used to entice students with varying levels of mathematical proficiency to pursue mathematics studies. Numerous people have concluded that mathematics learning and teaching should incorporate a variety of approaches, including the use of teaching aids proven to increase students' interest in mathematics. This is one of the most significant discoveries to the date. Mathematics teachers should have access to this software to provide students with a broader perspective on the world of mathematics and assist them in developing their critical and creative thinking abilities. GeoGebra is one of the mathematical software that is included on this list. Thus, increasing the use of ICT applications in the classroom to teach mathematics may assist students and instructors in contextualizing mathematical concepts.

7 Implications

We hope that our research will not be too unforgiving for everyone. GeoGebra may be used in mathematics education and learning, and some recommendations for utilizing GeoGebra in mathematics education and learning are included for readers, teachers, trainers, and researchers. Without a doubt, our study technique would be extremely beneficial to them because it would assist them in improving their ability to incorporate GeoGebra into their courses in order to concentrate and boost student learning in mathematics while also improving their own teaching abilities. Our findings are particularly relevant to mathematics instructors' classroom methods when teaching geometric transformation. Mathematics instructors who are unfamiliar with GeoGebra and those who are just starting their teaching careers will find this research effort to be eye-opening. According to our findings, to incorporate GeoGebra-based activities that promote thinking, instructors must have a strong understanding of mathematical ideas as well as the connections between various representations. To the end, our findings will assist policymakers and curriculum designers in implementing various ICT-integrated pedagogy.

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