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The Impacts of Using GeoGebra on Students' Perceptions and Achievement in Learning Geometric Transformations

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THE IMPACTS OF USING GEOGEBRA ON STUDENTS' PERCEPTIONS AND ACHIEVEMENT IN LEARNING GEOMETRIC TRANSFORMATIONS

A Dissertation

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December 2022

ABSTRACT

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This study aimed to contribute to the literature by examining the impacts of using GeoGebra on students' perceptions and achievement in learning geometric transformations. This study contributes to mathematics education and learning environments supported by GeoGebra. This study reviewed the literature on social constructivist learning theory and students' achievement in geometric transformations and perceptions of using GeoGebra. Nonequivalent control groups and a correlational research design were used to answer the research questions.

The participants were selected in six geometry classes from 9th-grade and 10th-grade students (n = 131). The method of selecting participants from the population was a convenience sample. The experimental group (n = 66) was taught using GeoGebra. In contrast, the control group (n = 65) was taught without using GeoGebra for a period of five weeks.

The data was collected from students' geometric transformations achievement test scores and a questionnaire from the experimental group to measure students' perceptions of using GeoGebra. A Kruskal-Wallis rank test was conducted to assess if there were significant differences in pretest scores between the group levels. The results of the Kruskal-Wallis test were not significant, based on an alpha value of .05, indicating the mean rank of the pretest score was similar for each level of the group. A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in gained test scores between the levels of the groups. The

results of the Kruskal-Wallis test were significant based on an alpha value of 0.05, indicating the mean rank of Gained test score was significantly different between the levels of the groups.

The questionnaire revealed information regarding students’ perceptions of using GeoGebra. A Spearman correlation analysis was conducted between students' perceptions of using GeoGebra and their geometric transformations achievement test. A significant positive correlation was observed between perceptions of using GeoGebra and the geometric transformations achievement test, with a correlation of 0.26, indicating a small effect size.

The summary statistics and percentages were used for the students' perceptions of using GeoGebra in learning geometric transformations. The results showed positive student perceptions of using GeoGebra in learning geometric transformations. The result also indicated that the GeoGebra helps students learn geometry concepts, visualize geometry content, and makes students more creative. The findings of this study showed that GeoGebra is an excellent tool for learning geometric transformations.

DEDICATION

Completing my doctoral degree would not have been possible without the love and support of my family. My wife, Sumeyra, and my daughter, Busra, wholeheartedly inspired, motivated, and supported me in every way to achieve this degree. Thank you for your love and patience.

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TABLE OF CONTENTS

Page

ABSTRACT ...…….……………………………………………………………………………..iii

DEDICATION.……………………………………………….…………………………….......v

ACKNOWLEDGMENTS…………..…………………………..…………………………......vi

TABLE OF CONTENTS…….……………………………………………………….…………vii

LIST OF TABLES………………………………………………………………..…………ix

LIST OF FIGURES……………………………………………………………..............xii

CHAPTER I. INTRODUCTION………………………………………………………….... 1

Statement of the Problem………………………………………………………………….2

Purpose of the Study………..………………………………………………………….4

Significance of the Study………...…………………………………………….…….6

CHAPTER II. REVIEW OF LITERATURE……………………...………..…………………9

Integrating Social Constructivist Learning Theory in Teaching and Learning Geometry..9

The Use of GeoGebra in the Learning Geometry………………………..……………12

Collaborative Learning Environment……………………………………..…………..14

Teaching and Learning Geometric Transformations………………………….....……17

Students' Perceptions of Using GeoGebra……………………...………………..……18

Summary……...…………………………………………………………………….....19

CHAPTER III. METHODOLOGY ………………….……………………..……………….… 21

Nonequivalent Control Groups Design and Correlational Research Design…...……....21

Data Collection……………………………………………………………………….....32

Data Analysis...……………………………………………………………...…......38

Summary………………………………………………………….………........41

CHAPTER IV. RESULTS……………………….……………………………………………42

The Impacts of Using GeoGebra on Students' Achievement in Geometric Transformations……………………………………..……………………...…43

Students' Perceptions of Using GeoGebra and Their Achievement in Learning Geometric Transformations…………………………….……..……………...…56

Students' Perceptions of Using GeoGebra in Learning Geometric Transformations……63

Summary……………………………………………………..……………………...…75

CHAPTER V. SUMMARY AND CONCLUSION…...…………………………...…………79

Discussion.………………………………………………………..………...…79

Conclusion…………………………………………………………………….87

REFERENCES…………………………………………………………...…...……91

APPENDIX A………..………………………………………………………………..96

APPENDIX B………..……..………..……………………………………………..117

BIOGRAPHICAL SKETCH...……………………………………………………………128

LIST OF TABLES

Page

Table 1: Demographic Characteristics of Participants.. .. .. ……...……...………….…..27

Table 2: Reliability Table for the Geometric Transformations Achievement Test…………….…..35

Table 3: Reliability Table for Questionnaire Items for Students' Perception of Using GeoGebra.………...……….………………………………………………………...……...37

Table 4: Chi-Square Goodness of Fit Test for Group…………………......………...…………..…..43

Table 5: Kruskal-Wallis Rank Sum Test for Pretest Score by Group……………………….…..44

Table 6: Kruskal-Wallis Rank Sum Test for Gained Test Score by Group……………………...45

Table 7: Pairwise Comparisons for the Mean Ranks of Gained Test Score by Levels of Group..45

Table 8: Kruskal-Wallis Rank Sum Test for Posttest Question 1-20 by Group……………..…..46

Table 9: Kruskal-Wallis Rank Sum Test for Posttest Question 2 by Group….……………..…..47

Table 10: Pairwise Comparisons for the Mean Ranks of Posttest Question 2 by Levels of Group……………………………………………………………………………….47

Table 11: Kruskal-Wallis Rank Sum Test for Posttest Question 14 by Group………………....48

Table 12: Pairwise Comparisons for the Mean Ranks of Posttest Question 14 by Levels of Group………………………………………………………………........49

Table 13: Kruskal-Wallis Rank Sum Test for Posttest Category 1-5 by Group……...………....50

Table 14: Kruskal-Wallis Rank Sum Test for Category 1: Rigid-Motion Transformations by Group……………………………………………………………………..….....51

Table 15: Pairwise Comparisons for the Mean Ranks of Category 1: Rigid-Motion Transformations by Levels of Group……………………………………………………......51

Table 16: Kruskal-Wallis Rank Sum Test for Posttest Difficult Level 1-3 by Group……..…......53

Table 17: Kruskal-Wallis Rank Sum Test for Hard Level 3 by Group……………………….....53

Table 18: Pairwise Comparisons for the Mean Ranks of Hard Level 3 by Levels of Group........54

Table 19: Spearman Correlation Results for PostQ1-PostQ20..55

Table 20: Spearman Correlation Results Between PostQ16 and PostQ19...................................56

Table 21: Spearman Correlation Results Between Students' Perceptions of Using GeoGebra and Students' Geometric Transformations Achievement Test……………………….…....58

Table 22: Spearman Correlation Results Item 6-Item 20……………………………………….....59

Table 23: Spearman Correlation Results Between I9 and I10……………………….……….....60

Table 24: Spearman Correlation Results Between I9 and I14…………………….…………......61

Table 25: Spearman Correlation Results Between I9 and I19…………………………..….......62

Table 26: Spearman Correlation Results Between I18 and I20……………………...……….....63

Table 27: Descriptive Statistics Table for Interval and Ratio Variables…………….………..64

Table 28: Frequency Table for Nominal Variables……………….…………………………..66

Table 29: Kruskal-Wallis Rank Sum Test for Perceptions of Using GeoGebra by Gender……..67

Table 30: Kruskal-Wallis Rank Sum Test for Perceptions of Using GeoGebra by Age……..….67

Table 31: Kruskal-Wallis Rank Sum Test for Perceptions of Using GeoGebra by Ethnic Background…………………………………...……………………………………......68

Table 32: Kruskal-Wallis Rank Sum Test for Questionnaire (Item 6 – Item 20) by Gender...….69

Table 33: Kruskal-Wallis Rank Sum Test for Questionnaire Item 19 by Gender……………......70

Table 34: Pairwise Comparisons for the Mean Ranks of Questionnaire Item 19 by Levels of Gender……………………………………...……………………………......70

Table 35: Kruskal-Wallis Rank Sum Test for Questionnaire (Item 6 – Item 20) by Age…….....71

Table 36: Kruskal-Wallis Rank Sum Test for Questionnaire (Item 6 – Item 20) by Ethnic Background…………………………...…………………………………………….....72

Table 37: Kruskal-Wallis Rank Sum Test for Geometry, Geometric Transformations, and Curriculum Related Items by Gender…………...……………………………….....73

Table 38: Kruskal-Wallis Rank Sum Test for Geometry, Geometric Transformations, and Curriculum Related Items by Age………………………………………………….....74

Table 39: Kruskal-Wallis Rank Sum Test for Geometry, Geometric Transformations, and Curriculum Related Items by Ethnic Background………………………………….....75

LIST OF FIGURES

Page

Figure 1: Adapted Research Procedure from Arbain and Shukor……………………………..…...23

Figure 2: Lizard Activity…………………………………………………………..…..…...31

Figure 3: Posttest Question 2…………………………………………………………..…...48

Figure 4: Posttest Question 14………………………………………………………....…...49

Figure 5: Sample Question for the Category 1: Rigid-Motion Transformations………………...52

Figure 6: Sample Question for the Hard Level 3………………………..…………………....54

Figure 7: Scatterplots with the regression line added for PostQ16 and PostQ19…………..…...56

Figure 8: Scatterplots with the regression line added for Perceptions of Using GeoGebra and Geometric Transformations Achievement Test……………….……………..…...57

Figure 9: Scatterplots with the regression line added for I9 and I10…..………………………...60

Figure 10: Scatterplots with the regression line added for I14 and I9…..….................................61

Figure 11: Scatterplots with the regression line added for I9 and I19…..………………………62

Figure 12: Scatterplots with the regression line added for I18 and I20…..…..............................63

Figure 13: Students' Perceptions of Using GeoGebra Item 14…..…...65

CHAPTER I

INTRODUCTION

The National Assessment of Educational Progress (NAEP) reported that most 12th-grade students showed no significant differences in overall mathematics scores from 2015 to 2019; the average score in mathematics did not change; and lower-performing students' scores decreased in mathematics and reading as compared to 2015 (Rahman et al., 2019). The National Council of Teachers of Mathematics (NCTM, 2014) emphasizes that technology is indispensable in improving students' achievement and meaningful mathematics learning. Besides, technology is an inescapable fact in today's world, an integral part of nearly all careers, and a powerful tool for mathematics (NCTM, 2014). NCTM (2000) considers technology one of the six school mathematics principles and states that technology is crucial in teaching and learning mathematics, has significant effects on teaching mathematics, and maximizes students' learning. Content-specific mathematics technologies, including dynamic geometry environments, support students in discovering and describing mathematical concepts and relationships (NCTM, 2015).

Abramovich (2013) encouraged using GeoGebra to teach and learn various subjects in any grade level, such as geometry, algebra, and calculus. The teacher has many vital roles in a technology-based classroom and in making decisions that affect students' learning of meaningful concepts (NCTM, 2000). The technology could provide visualizations and improve student achievement (Darling-Hammond et al., 2014).

Statement of the Problem

The effects of GeoGebra as a vital educational resource, an adequately designed corresponding curriculum that ensures technology integration in lessons, exploring GeoGebra's inputs, and added values in enhancing students' achievement and perceptions are areas that need more attention for future research (Wassie & Zergaw, 2019). High school students face challenges in learning geometry and often lack cognitive and process skills in understanding geometry concepts (Shadaan & Leong, 2013). Shadaan and Leong (2013) state that mathematics teachers may lack pedagogical strategies with effective geometry-learning environments and tools. Even though some learning tools, such as GeoGebra, a geometry learning online system, were used in the class, there is insufficient evaluative information to report on the learning tool's effectiveness. Thus, the research problems can be further divided into three aspects: a) Students lack cognitive and process skills in geometry learning, b) There are insufficient geometry learning tools to assist students in learning geometry, and c) There is no immediate evaluation and feedback of the learning tool such as GeoGebra.

In the teaching and learning of geometry, it has been noticed that students often lack cognitive and process skills in understanding geometry concepts (Shadaan & Leong, 2013). Shadaan and Leong (2013) stated that students face difficulties applying knowledge to complete their tasks in geometry concepts. Mathematics teachers could use technology to improve students' learning opportunities by choosing or creating mathematical activities that proficiently empower visualizing, graphing, and computing (NCTM, 2000). Therefore, students need to utilize beneficial dynamic geometry learning tools to understand and visualize geometry concepts.

The technology could be utilized wisely and responsibly to enrich students' learning in mathematics (NCTM, 2000). However, there are insufficient geometry learning tools to assist students in learning geometry. A literature review showed that using GeoGebra effectively improves students' understanding of geometry concepts. GeoGebra could play a role in filling up the gap by helping students visualize and understand geometry concepts through exploration (Garba, 2019). Shadaan and Leong (2013) also advised that GeoGebra could play a critical role in closing gaps in learning mathematics, and it helps students visualize and understand mathematics concepts through exploration. Haciomeroglu and Andreasen (2013) suggested that students develop a better geometrical understanding using GeoGebra.

GeoGebra plays an essential role in helping to clarify features that were not visible on the whiteboard (Adelabu et al., 2019). GeoGebra offers ways to represent and manipulate geometric objects that are impossible with paper, pencil, compass, or ruler. GeoGebra provides a platform for high-level thinking, particularly for teachers. At the same time, learners engage with the interactive features of the GeoGebra, such as learning from feedback, seeing patterns, making connections, and working with dynamic images (Adelabu et al., 2019). The authors stated that GeoGebra allows seeing the graphical, numerical, and algebraic representations of the geometry objects on the same screen as the graph displayed in the graphical view.

The study on the impacts of using GeoGebra on students' achievement contributes to the current literature regarding how GeoGebra improves students' achievement in learning geometric transformations (GT) and their perceptions of using GeoGebra.

Purpose of the Study

The first purpose of this study was to determine differences in high school students' understanding of geometric transformation concepts using GeoGebra. I analyzed the geometric transformations achievement test item by item, difficulty levels, and categories to provide detailed information for the first question. The second purpose of this study was to determine the relationships between students' perceptions of using GeoGebra and their geometric transformation achievement. I analyzed the students' perceptions of using the GeoGebra questionnaire item-by-item correlation analysis to provide detailed information for the second question. The third purpose of this study was to identify students' perceptions of using GeoGebra in learning geometric transformations. I also identified students' perceptions of using GeoGebra between the factor levels of the demographic characteristics and item analysis by category to provide detailed information for the third question.

Research Questions

This study addresses the following research questions:

Research Question 1: To what extent does teaching through GeoGebra affect students' achievement in geometric transformations?

Research Question 2: What is the relationship between students' perceptions of using GeoGebra and their geometric transformations achievement test?

Research Question 3: What are student perceptions about using GeoGebra in learning geometric transformations?

Hypothesis

Kutluca (2013) hypothesized that using GeoGebra could maximize students' learning of geometry concepts. The null and alternative hypotheses are related to the research questions in this study. The study investigated if there were statistically significant differences in the experimental and control groups' geometric transformation achievement posttest. I also proposed determining the relationship between students' perceptions of using GeoGebra and their geometric transformations achievement test. Also, this study aimed to identify the students' perceptions of using GeoGebra. Research hypotheses were developed based on data analysis and further discussion. This study addresses the following null hypothesis and alternative hypothesis:

Null Hypothesis (H_0) 1: No statistically significant difference exists in the experimental and control groups' geometric transformations achievement test (Gained test score).

Alternative Hypothesis (H_1) 1: A statistically significant difference exists in the experimental and control groups' geometric transformations achievement test (Gained test score).

Null Hypothesis (H_0) 2: No statistically significant relationship exists between students' perceptions of using GeoGebra and their geometric transformations achievement test.

Alternative Hypothesis (H_1) 2: A statistically significant relationship exists between students' perceptions of using GeoGebra and their geometric transformations achievement test.

Null Hypothesis (H_0) 3: Students generally provided negative feedback about using GeoGebra in learning geometric transformations.

Alternative Hypothesis (H_1) 3: Students generally provided positive feedback about using GeoGebra in learning geometric transformations.

Significance of the Study

This study contributes to mathematics education and learning environments supported by GeoGebra. Learning about the benefits of GeoGebra could be crucial to the students and mathematics teachers. Also, the mathematics department would benefit from this alternative teaching strategy to improve students' mathematics achievement. GeoGebra is a great tool to enhance the quality of mathematics learning, particularly for exploring, visualizing, and constructing mathematical concepts (Tamam & Dasari, 2021).

NCTM (2000) states that instructional programs from pre-kindergarten to 12th-grade students should apply geometric transformations and symmetry to analyze mathematical situations. In the approach advocated by the Common Core State Standards for Mathematics (i.e., Content Standard 8. G) (National Governors Association Center for Best Practices & Council of Chief State School Officers (2010), geometric transformations play a central role in understanding congruence and similarity. It should be introduced into the school curriculum because it encourages students to investigate geometry and develop abstraction and generalization power (NCTM, 2000).

GeoGebra provides teachers and students with a valuable tool to help students interact with mathematical concepts in a collaborative learning environment (Saha et al., 2010). Saha et al. (2010) stated that GeoGebra could be used in a collaborative learning environment based on the constructivist learning theory, particularly for teaching challenging mathematics concepts. Integrating GeoGebra impacts mathematics education and could promote student-centered learning and active learning (Saha et al., 2010). The authors stated that GeoGebra could be a helpful tool through visualization to encourage learning and enhance understanding.

Using GeoGebra in learning geometric transformations increases student motivation, engagement, and achievement, and students become more interested in learning geometry using the software because it provides a dynamic learning environment (Masri et al., 2016). Students' positive perceptions and beliefs toward learning geometry with dynamic geometry software GeoGebra could be fostered if students find learning geometry valuable and enjoyable (Ganesan & Eu, 2020).

Definition of Terms

The following terms were important in guiding the research study. Some terms may have multiple meanings, as referenced in journal articles or other online academic resources. Each term with an operational definition clarifies the meanings, descriptions, and definitions that apply to the research study. The terms are cited, so readers can further trace this information if needed. The list of terms is well-defined as follows in this study.

Geometry. Geometry is an essential branch of mathematics education, has a place in education to develop students' critical thinking and problem-solving skills (Serin, 2018).

GeoGebra. GeoGebra is a free and user-friendly mathematics software from primary school to university, including DGS and CAS features, and has been translated into over 50 languages. GeoGebra brings together geometry, algebra, spreadsheets, graphing, statistics, and calculus (Saha et al., 2010).

Achievement. Achievement is accomplished, especially by exertion, skill, practice, or perseverance (Thorndike & Barnhart, 1993). In this study, achievement means the total measurement of scores of geometric transformations pretest and geometric transformations posttest.

Geometric Transformations. Geometric Transformations are a subset of geometry in which students learn to identify and illustrate the movement of shapes in two and three dimensions, such as translation, reflection, rotation, and symmetry (Kirby & Boulter, 1999).

CHAPTER II

REVIEW OF LITERATURE

This chapter explores the significance of social constructivist learning theory in teaching and learning geometry. The chapter provides detailed information about collaborative learning practices, which allow constructing knowledge in the social context and integration technology; GeoGebra offers social interaction opportunities in teaching geometric transformations. The chapter explores the literature on students' achievement in geometric transformations and their perceptions of using GeoGebra. The chapter provides detailed information about the significance of geometric transformations with various concepts, including translations, symmetry, reflections, rotations, and others, and why GeoGebra was utilized in teaching GT.

Integrating Social Constructivist Learning Theory in Teaching and Learning Geometry

Students learn mathematics with understanding and actively construct new knowledge from experience and prior knowledge (NCTM, 2000). Building new knowledge could be socially playful in a social constructivist learning environment (Ernest, 1998). Lee and Hannafin (2016) stated that the student-centered approach plays a vital role in teaching and learning by integrating the social constructivist learning approach and learning practices such as discovery, active, inquiry-based, collaborative, and reciprocal learning.

Schunk (2019) stated that the social constructivist learning approach focuses on real-life adaptive problem-solving strategies that take place socially through shared experience and discussion with others. The social constructivist learning theory could create an effective teaching and learning classroom environment in mathematics (Herbst et al., 2017). The authors stated that integrating a student-centered learning environment involving exploration, manipulatives, and visual representations encourages students to develop necessary mathematical skills.

It is natural for geometry teaching to consider psychological theories of learning about space, shape, and quantity (Herbst et al., 2017). The authors expressed that constructivist learning theory advocates that students learn by actively listening, observing, and obtaining knowledge by building their understanding and adapting cognition to absorb their world experiences. They also stated that teaching geometry aims to help students develop and shape their understanding from real-life experiences.

Social Constructivism / Social Interaction

The social constructivist learning approach deals with the importance of collaboration with others, such as student and student or teacher and student, and social interaction as the primary tool for students to construct new meanings (Vygotsky, 1978). Teachers guide the students to learn rather than transfer knowledge and offer strategies that allow them to achieve or self-regulate conclusions. Students engage with their peers and the teacher in discussion and exploration in the social constructivist learning environment (Vygotsky, 1978). The social constructivist learning approach allows students to construct their knowledge in a social setting (Lopes et al., 2018).

Herbst et al. (2017) expressed that constructivist learning theory advocates that students learn by actively listening, observing, and obtaining knowledge by building their understanding and adapting cognition to absorb their experienced world. Curriculum designers should consider constructing contexts and activities to activate students' thinking because contexts and activities could play an essential role in creating contexts, including manipulatives and hands-on tasks (Herbst et al., 2017). The authors also stated that integrating a student-centered learning environment involving exploration, manipulatives, and visual representations encourages students to develop necessary mathematical skills.

Teachers and students could take the social constructivist learning environment role by building new knowledge on prior knowledge, using problem-solving strategies, and sharing understanding experiences with group members (Ernest, 1998). Shadaan and Leong (2013) stated that students are encouraged to work with their partners cooperatively and share experiences in a group. Innovative learning environments such as collaborative, inquiry-based, and problem-based learning are essential in specific content in learning mathematics by asking questions, investigating the topic, and using various valuable materials to find answers collaboratively (Uygun, 2020).

Shadaan and Leong (2013) asserted that students work with their peers to construct new knowledge and make observations according to their constructions in the social constructivist learning environment. The authors stated that GeoGebra's integration in learning mathematics is vital in scaffolding to bridge the zone of proximal development (ZPD). Social interaction allows students to cooperate and learn from their peers and knowledgeable others to reach their potential learning goals (Shadaan & Leong, 2013). The authors stated that self-exploration is fundamental in constructivist learning, allowing students to develop their understanding. They also further stated that visualization is crucial to grasping any mathematical concept. The authors stated that students create their knowledge by sharing experiences using the GeoGebra to explore and visualize their learning.

The Use of GeoGebra in Learning Geometry

In the twenty-first century, all students can understand and apply mathematics and integrate useful technology tools in learning mathematics (NCTM, 2000). The technology could help students investigate every mathematics area, such as algebra, geometry, statistics, measurement, and number (NCTM, 2000). Common Core State Standards Initiative (2010) stated that integrating technology has become part of everyday life, and students could use technology in the classroom. Technology is crucial in teaching and learning mathematics, impacting teaching and improving students' learning (NCTM, 2000).

Teachers could use technology to improve students' understanding by selecting or constructing mathematical activities like graphing, visualizing, and computing (NCTM, 2000). Majerek (2014) stated that integrating GeoGebra in teaching and learning mathematics provides students with different mathematical skills and a better understanding of concepts. GeoGebra should be introduced to mathematics educators so that students can explore the world of mathematics more comprehensively and think critically and creatively (Arbain & Shukor, 2015). Kutluca (2013) stated that students understand geometry concepts better when integrating GeoGebra in geometry classes.

Teaching and learning mathematics with technology motivates, engages, and encourages teachers and students (Ozdamli et al., 2013). Technology and software could make it easier to understand mathematics and improve students' motivation and self-confidence (Shadaan & Leong, 2013). Shadaan and Leong (2013) asserted that GeoGebra positively affects students' understanding of geometry concepts. The authors stated that the experimental group using GeoGebra performed better than the control group using the traditional teaching method. Their results indicated that students who had learned the topics using GeoGebra performed better than students who had learned the topics without using GeoGebra.

Saha et al. (2010) reported that students who utilized GeoGebra scored better than students who learned traditional teaching methods. The authors found that GeoGebra is helpful for teaching geometry concepts and more effective than conventional teaching methods. They further stated that integrating technology in geometry topics could help students understand the visual images of mathematical ideas, organize and analyze data, and compute efficiently and accurately. GeoGebra creates a productive learning environment, such as constructing dynamic shapes, moving shapes, forming multiple representations, and analyzing concepts (Saha et al., 2010). The authors found that by using GeoGebra, students could better understand shapes' properties and geometric transformations. They further stated that GeoGebra could simulate realistic learning environments in mathematics to construct geometric shapes, manipulate and move them, visualize and analyze them, and make conjectures.

Zengin et al. (2012) reported a significant difference between the control group's mean achievement scores and the GeoGebra group when the GeoGebra was integrated into teaching and learning mathematics. GeoGebra integration into teaching and learning mathematics enhances students` mathematics achievement (Saha et al., 2010). They also reported that integrating GeoGebra is more effective than traditional teaching methods in teaching coordinated topics.

Recent studies showed that GeoGebra integration in geometry improves students' achievement (Jelatu & Ardana, 2018; Singh, 2018). They confirmed that using GeoGebra in teaching and learning geometry allows students to explore the concepts and develop their knowledge of geometry. Many studies compared students' achievements between the experimental group taught with GeoGebra and the control group without GeoGebra in the traditional teaching approach (Jelatu & Ardana, 2018; Khalil, 2017; Khalil et al., 2018; Masri et al., 2016; Seloraji & Eu, 2017; Shadaan & Eu, 2013; Singh, 2018). This study contributes to the literature by examining the impacts of GeoGebra in a collaborative learning environment.

Collaborative Learning Environment

The social constructivism learning approach encourages collaborative learning among students and teachers (Schunk, 2019). Mathematics teachers are responsible for student learning collectively, improving the professional knowledge base, and everyone's effectiveness (NCTM, 2014). Bishnoi (2017) stated that collaborative learning is an educational approach to learning involving groups working on activities to solve the problem, complete the activities, or create the product. The collaborative learning approach utilizes students' social experiences to encourage their involvement in learning (Ezeanyanike, 2013). Bwalya (2019) stated that social interactions between students allow them to guide one another to reach a level of shared understanding.

Collaborative learning involves the teamwork of students who learn by working together to solve problems, share ideas, or achieve common goals (Lahann & Lambdin, 2020). Collaboration is an essential learning method of students' participation that should advance the twenty-first-century trend (Laal & Ghodsi, 2012).

All students should have access to technology to facilitate their mathematics learning under skillful guidance from the teacher (NCTM, 2000). Laal and Ghodsi (2012) stated that students could share prior knowledge and participate in collaborative learning activities to construct new knowledge from a social constructivist perspective. There are several practical reasons social constructivism learning focuses on integrating a collaborative learning approach in teaching and learning (Laal & Ghodsi, 2012). The authors stated that collaborative learning has numerous benefits.

Develop Social Interaction Skills

Students develop social interaction skills in collaborative learning environments (Ezeanyanike, 2013). Collaborative learning could support constructing and developing social interaction skills. Social interaction helps students learn from others, gets students interested and engaged, makes learning fun, and allows them to talk in the classroom (Hurst et al., 2013). The collaborative learning approach helps to develop a social support system (Laal & Ghodsi, 2012). The authors stated that collaborative learning helps to build diverse understanding between students and teachers. They also further stated that collaborative learning creates a constructive learning environment for modeling and practicing with learning communities.

Allow Learning from Peers

Collaborative learning allows students to establish their knowledge by helping their peers (Shadaan & Leong, 2013). The authors stated that the social interaction between the peers permitted the students to guide one another and reach a level of shared understanding. They also further stated that the higher ability students play a significant role in helping the lower ability students to achieve their tasks.

Role Playing to Real-Life Experiences

Students could be assigned roles within their group in society and the real world (Schunk, 2019). Bonwell and Eison (1991) stated that role plays could be effectively used in the classroom to provide real-world scenarios to help students learn. These roles can be performed by individual students, in pairs, or in groups which can play out in more complex problems and real-life situations (Bonwell & Eison, 1991).

Build Self-Esteem

Students could get lots of advantages from a collaborative learning environment. They could help and support each other in a student-centered learning environment with a collaborative learning approach that increases students' self-esteem (Laal & Ghodsi, 2012). The authors stated that student-centered teaching increases students' self-esteem. They also further stated that collaborative learning reduces math anxiety.

Develop Problem-Solving Skills

Students work together, are responsible for others' learning, and develop problem-solving skills by receiving immediate feedback, discussing, responding to their peers' questions and comments, and formulating their ideas (Lopes et al., 2018).

Promote Critical Thinking Skills

Efforts to develop critical thinking skills have become the main agenda in the mathematics education curriculum (NCTM, 2000). Integrating critical thinking skills in mathematics education could improve students' achievement (Firdaus et al., 2015; NCTM, 2000). Additionally, critical thinking skills encourage students to think independently and solve problems in everyday life (NCTM, 2000). Critical thinking skills could be part of students' learning, and schools and teachers play an essential role in developing and evaluating their critical thinking skills (Firdaus et al., 2015). The authors stated that mathematics teachers could teach mathematics content and develop students' critical thinking skills to solve various school or social life problems. Critical thinking skills in mathematics are closely associated with open-ended mathematical problems, problem-solving in mathematics, and contextual problems that challenge students to solve the problem to encourage mathematical thinking (NCTM, 2000).

Increase Retention

Students are active learners and involved in the learning process. The interactive learning environment connects to collaborative learning in students' motivation and participation and maximizes student retention (Zengin & Tatar, 2017). It also encourages a positive attitude toward the subject matter and increases student retention (Ezeanyanike, 2013).

Laal and Ghodsi (2012) stated that collaborative learning helps students be actively involved in the learning process. The authors stated that collaborative learning supports students in using appropriate models for problem-solving methods and operates various assessments. They also further stated that collaborative learning is helpful to motivate students in a specific curriculum.

Teaching and Learning Geometric Transformations

Effective mathematics teaching requires understanding what students know and need to learn and challenging and supporting them to learn well (NCTM, 2000). Improving mathematics education for all students could be accomplished by teaching mathematics effectively, and it requires reflection and continual efforts to seek improvement (NCTM, 2000). It makes sense and makes students more comfortable remembering and applying when students construct new knowledge to learn mathematics (Polman et al., 2020). Students learn well when they control their learning by defining their goals, monitoring their progress, and recognizing the importance of reflecting on their thinking and learning from their mistakes (NCTM, 2000).

Although middle school students have experiences with fundamental Geometric Transformations (GT), such as translations, reflections, rotations, and dilations, high school students learn to represent GT with matrices and explore the transformations' properties using graph paper and dynamic geometry software (NCTM, 2000). GT is related to other geometry concepts, such as similarity and congruence, algebra, patterns, and functions in mathematics, as well as the idea of tessellations in mathematical reasoning (Uygun & Akyuz, 2019).

Uygun (2020) posited that GeoGebra could help students improve their mathematical ideas in GT. The author states that collaborative learning activities could play an essential role in a learning environment supported by GeoGebra with the class community. Uygun (2020) suggested that GeoGebra could be beneficial for improving students' understanding of mathematical concepts. Shadaan and Leong (2013) stated that students have challenges understanding geometry concepts; therefore, the GeoGebra could be used as a scaffold to improve students' understanding of geometry.

Students' Perceptions of Using GeoGebra

Technology tools could enhance students' perceptions and motivation in learning mathematics (Masri et al., 2016). Joshi and Singh (2020) stated that students perceive GeoGebra as an effective tool in learning mathematics, understanding mathematical concepts, increasing their confidence in solving problems, making them more creative, making learning more enjoyable, and visualizing mathematical content. Shadaan and Leong (2013) also asserted that integrating GeoGebra in teaching and learning mathematics could increase students' interest, confidence, and inspiration. The authors noted that integrating useful technological tools in teaching and learning mathematics improves students' achievement and motivation. They also found that GeoGebra allows teachers and students to communicate effectively.

Arbain and Shukor (2015) found similar results about students' perceptions. Arbain and Shukor (2015) stated that students positively perceive using GeoGebra with enthusiasm, confidence, and motivation. Joshi and Singh (2020) found that GeoGebra is an excellent tool for conceptualizing and visualizing mathematical content. Furthermore, Lavicza and Prodromou (2017) and Wah (2015) showed that GeoGebra is an effective mathematics software in learning mathematics related to student attitude, attention, relevance, and confidence.

Ganesan and Eu (2020) found that students who use dynamic geometry software enjoyed geometry and found the lesson more interesting. The authors found that the result obtained from the students' perception questionnaire from the experimental group shows positive feedback, which implied that learning geometry with dynamic geometry software had been beneficial for the students. Shadaan and Leong (2013) stated that technology in learning geometry helps create a less stressful environment for teachers and students. The classroom environment could be more enjoyable and fun when the students communicate and participate in classroom discussions with teachers and friends (Ganesan & Eu, 2020). Arbain and Shukor (2015) stated that dynamic geometry software such as GeoGebra could help students improve their perceptions and learning of geometry. Interactive software can promote student participation and cooperative learning. Masri et al. (2016) stated that GeoGebra in teaching geometry could be used in classrooms to increase students' engagement and achievement with GeoGebra to improve motivation and involvement and student' perceptions about using technology to understand their willingness and ability to use technology in geometry classes.

Summary

The chapter began with a discussion of the social constructivist learning theory and focused on the importance of social constructivist learning theory in teaching and learning geometry. Several effective teaching and learning educational practices were presented in this chapter, such as collaborative learning and GeoGebra's integration into teaching and learning geometry. This chapter reviewed previous studies regarding the impacts of a collaborative learning environment, incorporating GeoGebra in learning geometric transformation, and students' perceptions of using GeoGebra. Besides, I provided detailed information about the significance of geometric transformation concepts, including translations, symmetry, reflections, rotations, and the importance of utilizing GeoGebra in teaching geometric transformations.

Wassie and Zergaw (2019) suggested future researchers investigate the impacts of GeoGebra to enhance students' achievement and perceptions. Besides, students find geometry challenging and lack cognitive and process skills in learning geometry concepts (Shadaan & Leong, 2013). Teaching mathematics effectively requires teachers to be skilled at teaching methods that improve meaningful mathematics learning (NCTM, 2014). Integrating technology (NCTM, 2000), specifically GeoGebra (Shadaan & Leong, 2013), was suggested in recent studies. Therefore, this study contributed to the current literature by examining the impacts of using GeoGebra on students' achievement and perceptions.

CHAPTER III

METHODOLOGY

Nonequivalent Control Groups Design and Correlational Research Design

I used a nonequivalent control group design and a correlational research design to answer the research questions in this study. I conducted this study between October 4, 2021, and November 5, 2021, in a public charter school in the south-central region of the United States.

Nonequivalent Control Groups Design

Gravetter and Forzano (2019) stated that an experimental group receives a pretest, treatment, and then a posttest in the nonequivalent control group design. At the same time, a nonequivalent control group gets a pretest, no treatment, and a posttest (Gravetter & Forzano, 2019). Therefore, the question is not simply whether participants who receive treatment improve, but whether they improve better than participants who do not (Gravetter & Forzano, 2019). In a nonequivalent control group design, there is no random assignment and no assurance of equivalent groups (Gravetter & Forzano, 2019). This design is appropriate for my study because I could not assign students randomly, and I selected the classes that took Geometry in the 2021-2022 school year.

Correlational Research Design

The structure of a correlational research study was selected to examine the relationship between students' perceptions of using GeoGebra and achievement in learning geometric transformations. An experimental group of participants with two scores, students' perceptions of using GeoGebra and achievement in learning geometric transformations, was measured for each individual.

The research procedure contained four phases. The first phase was the geometric transformations achievement test consisting of 20 multiple-choice questions on the experimental and control groups. The second phase was the experimental group's intervention phase using GeoGebra, while the control group was taught without using GeoGebra. The third phase was the post-achievement test for both groups in the fifth week. Only the experimental group answered the questionnaire containing 15 items using the Likert scale to determine students' perceptions of using GeoGebra in the fourth phase (Appendix B). After collecting data, the test results were calculated to determine whether GeoGebra affects students' GT achievement test scores. The questionnaire also determined students' perceptions of using GeoGebra in learning GT. Figure 1 represents an adapted research procedure from Arbain and Shukor (2015).

Phases	Control Group	Experimental Group
Phase 1	↓ Geometric transformations achievement test (Pretest)	↓ Geometric transformations achievement test (Pretest)
Phase 2	↓ Teaching geometric transformations without GeoGebra	↓ Teaching geometric transformations with GeoGebra
Phase 3	↓ Geometric transformations achievement test (Posttest)	↓ Geometric transformations achievement test (Posttest)
Phase 4	↓ Not Administer questionnaire	↓ Administer questionnaire

Figure 1: Adapted Research Procedure from Arbain and Shukor (2015)

Before the treatment, students in the experimental group were trained to use GeoGebra since it was new. Students learned the functions of the buttons, such as drawing a line, segmenting and forming a polygon, dragging and constructing bisectors, and measuring length, area, and angle. The teacher spent 24 sessions, 45 minutes each, teaching geometric transformation concepts. The control and experimental group received the same curriculum materials for each lesson. While the experimental group used GeoGebra, the control group did not use GeoGebra. After collecting data, the test results were analyzed to determine whether there was a significant difference between the experimental and control groups. The questionnaire provided information about students' perceptions of using GeoGebra.

Threats to the Validity

This is a nonequivalent control group design. This design considers some threats, such as statistical regression, selection treatment interaction, and pretest treatment interaction.

Statistical Regression. This is a nonequivalent control group design where subjects are assigned to a treatment or control group based on their accessibility. Statistical regression concerns arise when participants are selected based on their extremely high or low scores. Random sampling representing the full range of scores could be used to address these internal validity concerns. Of six classes enrolled in Geometry class in the 2021-2022 school year, three classes were assigned randomly to the experimental group.

Selection Treatment Interaction. The nonrandom selection of participants restricts the generalizability of the study. The selection treatment interaction refers to nonrepresentative participants of the population, and the participants had similar mathematics abilities at the beginning of the study. Then, the threats for selection-treatment interaction did not affect the inferences made in this study. The Selection Treatment Interaction concerns a researcher's ability to generalize a study's results beyond the groups involved. Results should only be generalized to the population who could have been chosen randomly to participate. When it is not possible to randomly assign participants to groups, the experimental design provides adequate control of threats to validity (Mills & Gay, 2019). The groups of participants were selected to be as equal as possible to reduce the threats and increase the study's validity (Mills & Gay, 2019).

Pretest Treatment Interaction. The pretest treatment interaction sensitizes the participants to different aspects of the treatment and thus influences their posttest results. In other words, the pretest treatment interaction could sensitize participants to the treatment's nature and potentially make the treatment effect different than it would be had participants not been pretested. Mills and Gay (2019) recommended that a pretest on algebraic algorithms would have little impact on a group's responsiveness to a new teaching method. I used the geometric transformations achievement test (Appendix A). According to Mills and Gay (2019), I do not expect that the pretest impacts the treatment.

Sample

Students. The participants were selected in six geometry classes from 9th-grade and 10th-grade students (n = 131). Although six geometry classes were randomly assigned to control and experimental groups, participants were not randomly assigned to the control and experimental group and were selected based on their accessibility.

The method of selecting participants from the population was a convenience sample, as each teaching method is conducted in preexisting classes of students (Mills & Gay, 2019). Mills and Gay (2019) stated that convenience sampling is one sampling method where participants were selected because they are easily accessible to the researcher. Convenience sampling is a non-randomized sampling strategy where participants are selected because they are readily available (Stockemer, 2018). The participants could be removed from this study if they do not want to participate or discontinue at any time and without any questions asked.

The experimental and control groups took the geometric transformations achievement pretest and posttest and evaluated their geometric transformation achievement test scores. The geometric transformations achievement pretest and posttest contained identical items with 20 multiple-choice questions (Appendix A). The questionnaire for students' perception of using

GeoGebra was conducted for the only experimental group to determine the relationship in students' perceptions of using GeoGebra at the end of the treatment process.

Only six classes enrolled in the Geometry course in the 2021-2022 school year at the school where this study was conducted, so six geometry classes were selected for this study. Three geometry classes were selected randomly for the experimental group, and the other three geometry classes were selected for the control group. The experimental group ($n = 66$) was taught using GeoGebra. In contrast, the control group ($n = 65$) was taught without using GeoGebra for a period of five weeks. Each group was administered a pretest and posttest to determine students' achievement in GT. A pretest was distributed for both groups to determine whether each group had similar mathematics abilities at the beginning of the study and other demographic data comparisons (Creswell, 2015). A Kruskal-Wallis rank test was conducted to assess if there were significant differences in Pretest scores between the levels of the Group. The results of the Kruskal-Wallis test were not significant, based on an alpha value of .05, indicating the mean rank of the pretest score was similar for each level of the group. Therefore, the experimental and control groups had similar mathematics abilities at the beginning of the study. Table 1 represents the frequency of demographic characteristics of participants.

Table 1

Demographic Characteristics of Participants

Demographic Characteristics	Control Group n	%	Experimental Group n	%
Gender Information				
Female	31	47.7	31	47.0
Male	34	52.3	35	53.0
Age Information				
Under 15 years old	35	53.8	36	54.5
15 years old	25	38.5	25	37.9
16 years old	3	4.6	3	4.5
Above 16 years old	2	3.1	2	3.0
Ethic Background				
Hispanic	49	75.4	51	77.3
Asian	3	4.6	2	3.0
Black or African American	6	9.2	5	7.6
White	7	10.8	8	12.1

Note. N = 131 (n = 65 for control group and n = 66 for experimental group)

The high school mathematics courses sequence in Algebra 1, Geometry, Algebra 2, and Precalculus. Some students take Algebra 1 in 8th grade, so they take Geometry in 9th grade, and on-level students take Geometry in 10th grade. Therefore, participants of this study were selected from 9th-grade and 10th-grade students. Ninth-grade and 10th-grade students (n = 131) participated in this study because they took Geometry courses. The participants already took the Algebra 1 course the previous year and are ready to take the geometry course this year.

Teacher. I, a researcher, work as a district mathematics department head at a public charter school district. I selected the teacher who taught Geometry in one of the high schools in my district. The teacher has taught middle school mathematics courses for five years and high school geometry for three years. He was 35 years old at the time of the study. He completed a bachelor's degree in mathematics and a master of education degree in the educational leadership program. He is a certified mathematics teacher from 5th grade through 12th grade. The same mathematics teacher taught experimental and control groups.

The role of the teacher is more of a facilitator, which encourages students to participate in the lesson actively and make significant connections. Ezeanyanike (2013) stated that the teacher plays a vital role in facilitating the social learning environment and creating positive interaction between students in the learning environment. I provided lesson plans for each lesson and had meetings with the teacher regarding integrating GeoGebra into the lessons. I observed his classes several times to make sure he implemented lesson plans. One of my responsibilities in the district is observing the classes and providing feedback to mathematics teachers. Therefore, students were used to seeing me in their classes, and it did not impact students' or the teacher's performance.

The Study Content Domains in Geometric Transformations

Geometric transformations (GT) is one of the main concepts of geometry. Each point is moved under a specific GT involving rotation, translation, reflection, and compositions, mapping their preimage points to other points on the plane (Uygun, 2020). Students could learn GT with physical experiences such as slides (translations), turns (rotations), and flips (reflections) (NCTM, 2000). All high school students could comprehend and represent translations, rotations, reflections, and dilations of objects in the plane by utilizing sketches, coordinates, vectors, function notation, matrices, and various representations to comprehend the effects of simple transformations and their compositions (NCTM, 2000). Therefore, teachers could ask students to visualize and describe the relationship among centers of rotation, lines of reflection, and positions of preimages and images (NCTM, 2000). The study has content domains in geometric transformations (Reflection, translation, rotation, classification of rigid motions, and symmetry).

Reflection. Students explored and applied their knowledge in identifying rigid motions, reflecting a figure across a line, reflecting a figure on a coordinate plane, describing a reflection on the coordinate plane, and using reflections. Reflections are rigid motions across a line of reflection. Students created images, given preimages and the line of reflection, both with and without a coordinate plane. Students learned the new vocabulary, which is a rigid motion. Students found reflected images, wrote rules for a reflection, defined reflection as a transformation across a line of reflection with given properties, and performed reflections on and off a coordinate grid.

Translation. Students explored and applied their knowledge in finding the image of a translation, writing a translation rule, composing translations, relating translations and reflections, and proving the reflections across parallel lines theorem. A translation is a rigid motion that moves all points of the preimage at the same distance in the same direction, and a translation is the composition of two reflections. The new vocabulary learned in this lesson is the composition of rigid motion. Students translated figures and wrote a rule for a translation, found the image of a figure after the composition of rigid motions, and proved that a translation is a composition of two reflections.

Rotation. Students explored and applied their knowledge in drawing a rotated image, drawing rotations in the coordinate plane, using rotations, investigating reflections and rotations, and proving reflections across intersecting lines. Rotation is a rigid motion described by its center of rotation and angle of rotation. Any rotation can be explained by two reflections whose lines of reflection meet at the center of rotation at half the angle of rotation. Students rotated figures, wrote rules for rotations, and proved that a rotation could be written as the composition of two reflections.

Classification of Rigid Motions. Students explored and applied their knowledge in analyzing glide reflections, finding the image of a glide reflection, and determining any glide reflection. Any composition of rigid motions can be represented by a combination of a translation, reflection, rotation, or glide reflection. A new vocabulary was learned in this lesson, a glide reflection. Students specified a sequence of transformations that carry a given figure onto another and used geometric descriptions of rigid motions to transform figures.

Symmetry. Students explored and applied their knowledge in identifying transformations for symmetry, identifying lines of symmetry, identifying rotational symmetry, determining symmetries, and using symmetry. A figure that can be mapped onto itself using rigid motions is symmetric, and rotations and reflections can map a figure onto itself. The new vocabularies were learned in this lesson: point symmetry, reflectional symmetry, and rotational symmetry. Students described the rotations and reflections that carry a polygon onto itself, predicted the effect of a given rigid motion on a figure, and identified types of symmetry in a figure. Figure 2 represents a sample activity, lizard activity, which was created with GeoGebra.

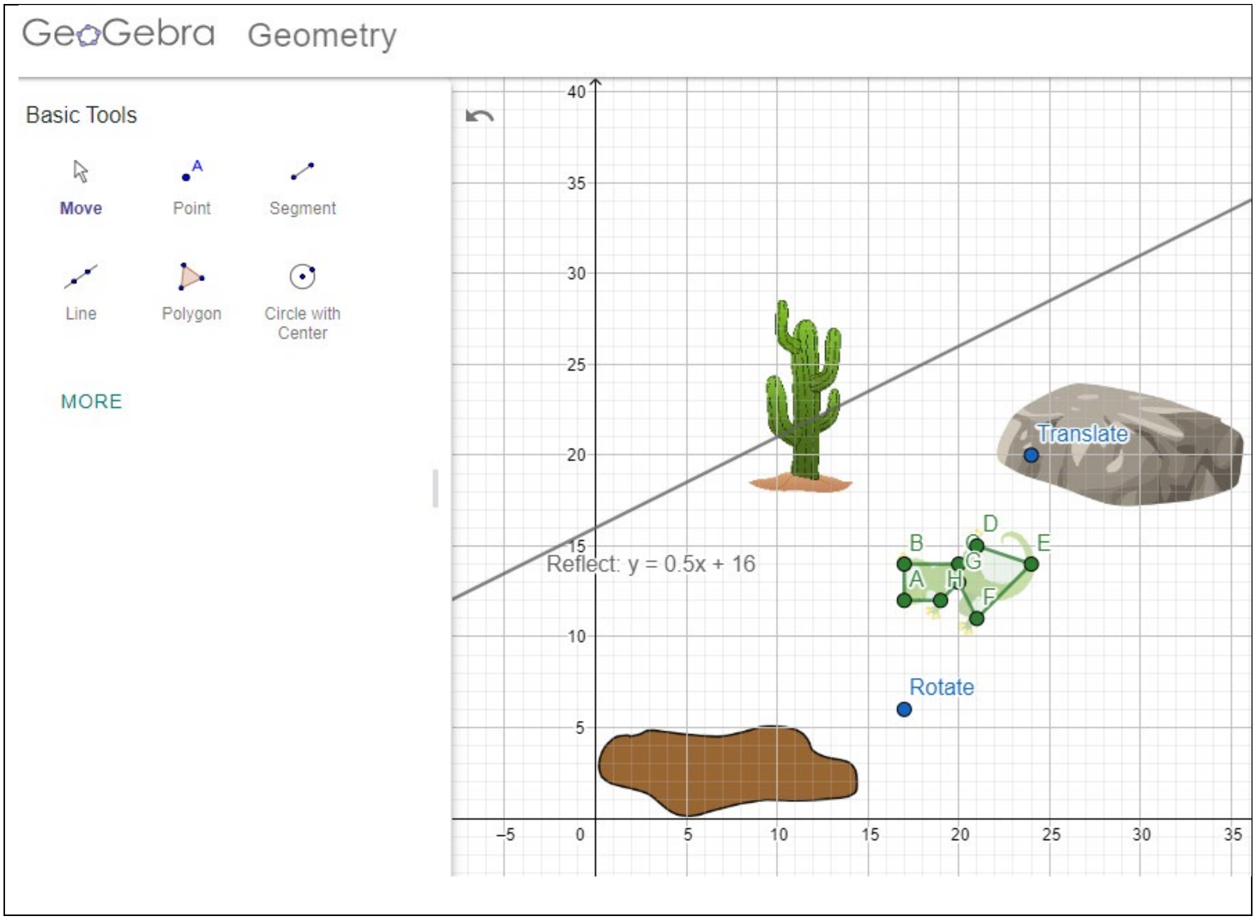


Figure 2: Lizard Activity

Conditions

Three geometry classes participated in the experimental group, and three geometry classes in the control group. There were about 25 students in each of the classes. In both experimental and control groups, students were engaged in the same district curriculum and teaching pedagogical approaches to promote their development of GT. The teaching content for the experimental and control groups was identical. All participants took the same GT achievement test and solved the same questions in the same classroom learning environment. I assumed that students answered the questions honestly. The participants from the experimental and control groups had similar mathematics abilities, as verified by analyzing pretest scores.

Each session was 45-minute long, and students had five geometry sessions per week. Participants in both conditions participated in 24 sessions of GT instruction, including assessments.

Variables

Several variables were considered dependent variables or independent variables in this study. The dependent variables in this study were geometric transformations achievement pretest and posttest and perceptions of using GeoGebra (Questionnaire). A Kruskal-Wallis rank test was conducted to assess if there were significant differences in the geometric transformations achievement pretest scores between the levels of the groups. After that, the gained test score of the geometric transformations achievement test was calculated as differences between geometric transformations achievement posttest and geometric transformations achievement pretest. The independent variables in this phase of the study were the level of groups: the control and the experimental groups. While the control and experimental groups were independent variables, the geometric transformation achievement posttest was the dependent variable. Then, A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in gained test scores between the levels of the groups. A Spearman correlation analysis was conducted between students' perceptions of using GeoGebra and their geometric transformations achievement test. This study also used descriptive statistics for the students' perceptions of using GeoGebra in learning geometric transformations.

Data Collection

The data was collected from students' GT achievement test scores of the experimental and control groups and from the questionnaire that was only assigned to the experimental group to measure students' perceptions of using GeoGebra. After the pretest administration, the same set of lessons was provided to both groups, covering the entire unit of GT. The geometric transformations unit is the third unit in the school curriculum, and the teacher covered the lesson between October 4, 2021, and November 5, 2021, in five weeks. Therefore, this study began in the first week of October 2021. The experimental group was taught with GeoGebra, and the control group was taught without GeoGebra. The posttest was administered to participants to measure how much they learned from teaching with GeoGebra and without GeoGebra after covering the GT unit. At the end of the study, the experimental groups took the students' perceptions of using the GeoGebra questionnaire.

Research Instruments

The geometric transformations achievement test and the students' perceptions of using the GeoGebra questionnaire were used in this study.

Geometric Transformations Achievement Test. The pretest was used to determine the achievement level of students in both groups. Posttest was to measure the students' achievement after the treatment. The pretest and posttest had the same questions and structure. The test consisted of 20 multiple-choice questions, and all participants solved the questions without using GeoGebra. I was able to find ten questions from the Trends in International Mathematics and Science Study (TIMSS) mathematics sample questions and the National Assessment of Educational Progress (NAEP) mathematics assessment related to geometric transformations. I created the rest of the questions from the school curriculum to have more pretest and posttest items. Reliability of the pretest and posttest was measured and assured by using Cronbach's alpha test. Five mathematics teachers reviewed the instrument to ensure content validity. I categorized the questions into five categories; four questions related to translation, four to rotation, four to symmetry, four to reflections, and the rest to rigid-motion transformations.

The data were obtained from the geometric transformations achievement test. In the evaluation of 20 multiple-choice questions, including the geometric transformations achievement test; "1 point" was given for each correct answer for easy/level 1 questions (Questions: 15 and 18), and "0 points" was given for each incorrect answer; "2 points" was given for each correct answer for medium/level 2 questions (Questions: 3, 4, 6, 7, 8, 9, 11, 12, 14, and 16) and "0 points" was given for each incorrect answer; "3 points" was giving for each correct answer for hard/level 3 questions (Questions: 1, 2, 5, 10, 13, 17, 19, and 20) and "0 points" was given for each incorrect answer. After this scoring, the minimum total score obtained from the test was determined "0 points," and the maximum total score obtained from the test was determined "46 points".

The Validity of the Instruments. Five experienced mathematics teachers reviewed the instrument's content validity. Evidence-based on the test content we use to measure achievement tests in education, including a panel of experts providing evidence of whether the test's content relates to the test's intended measure (Creswell, 2015). Five experienced mathematics teachers validated the test questions on the concepts, categories, and difficulty level and came up with 100% agreement on the validity of the geometric transformations achievement test questions. They reviewed the test for the content validity of the developed tests and the items' accuracy. Their comments and recommendations were used to improve the test questions. For example, one of the reviewers provided feedback about a mistake in answer to question 15, and I corrected the mistake. I made necessary corrections based on the feedback received, and the GT achievement test was finalized.

The Reliability of the Instruments. It is also essential to examine the instrument's reliability or the GT achievement test's internal consistency to produce consistent results over time. To this end, I conducted a pilot study detailed below where the instrument was implemented with a sample of 11^{th}-grade students (n = 32) who had already taken the geometry course and took the geometric transformations achievement test during a 45 minutes class period in September 2021. After administering the pilot study, a Cronbach alpha coefficient was calculated for the test consisting of 20 multiple-choice questions from the GT's achievement test scores. The test's reliability was evaluated by administering the pilot study to high school students who did not participate in the study. The data was analyzed to calculate Cronbach's alpha value to measure the test's internal consistency.

I conducted a pilot study to measure the pretest and posttest content validity, reliability of the test, and internal consistency in September 2021. For the pilot study, high school students (n = 32) were assigned the test during a 45 minutes class period. A Cronbach alpha coefficient was calculated for the geometric transformations achievement test, consisting of 20 multiple-choice questions. The Cronbach's alpha coefficient was evaluated using the guidelines suggested by George and Mallery (2020) where > 0.9 excellent, > 0.8 good, > 0.7 acceptable, > 0.6 questionable, > 0.5 poor, and ≤ 0.5 unacceptable. The geometric transformations achievement test items had a Cronbach's alpha coefficient of 0.83, indicating good reliability. Table 2 presents the reliability analysis results for the geometric transformations achievement test.

Table 2

Reliability Table for the Geometric Transformations Achievement Test

Scale	No. of Items	α	Lower Bound	Upper Bound
Geometric Transformations Achievement Test	20	.83	.76	.90

Note. The lower and upper bounds of Cronbach's α were calculated using a 95.00% confidence interval.

Questionnaire. Recent studies used a questionnaire about students' perceptions of using GeoGebra in their studies (Arbain & Shukor, 2015; Bayaga et al., 2019; Joshi & Singh, 2020; Shadaan & Leong, 2013). I used these studies to create questionnaire items for the current research.

The data were obtained from the questionnaire about students' perceptions of using GeoGebra. The questionnaire has two sections; general information and students' perceptions of using the GeoGebra. The first section includes the student's name, section, gender, age, and ethnic background items. The second section contains students' perceptions of using GeoGebra items. I used the questionnaire of students' perceptions of using the GeoGebra to find the correlation between students' achievement test scores and their perceptions of using GeoGebra.

The questionnaire contained statements that reflect the students' perceptions of using GeoGebra. The students' perceptions of using GeoGebra questionnaire items were designed with a Likert scale of Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree. In the coding of 15 items in the students' perceptions of using the GeoGebra questionnaire, "1" was given for Strongly Disagree, "2" was given for Disagree, "3" was given for Neutral, "4" was given for Agree, and "5" was given for Strongly Agree. After this coding, the minimum total score obtained from the test was determined "15," and the maximum total score obtained from the test was determined "75".

The Validity of the Instruments. Five experienced mathematics teachers and two experienced English teachers reviewed the questionnaire to validate it. They validated the questionnaire and came up with 100% agreement on the validity of the statements on the questionnaire. Their comments and recommendations were used to improve the questionnaire statements. I made necessary corrections based on the feedback received, and the questionnaire was finalized.

The Reliability of the Instruments. The students' perceptions of using GeoGebra questionnaire items were designed with a Likert scale of 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, and 5-Strongly Agree. A Cronbach alpha coefficient was calculated for the questionnaire consisting of statements. The questionnaire's reliability was evaluated by administering the pilot study to high school students who did not participate. The data was analyzed to calculate Cronbach's alpha value to measure the questionnaire's internal consistency.

I conducted a pilot study to measure the reliability of the questionnaire in September 2021. For the pilot study, randomly selected 11th-grade high school students (n = 30) who use GeoGebra were assigned the questionnaire during a 45 minutes class period. A Cronbach alpha coefficient was calculated for the students' perceptions, consisting of 15 questionnaire items for students' perceptions of using GeoGebra. The Cronbach's alpha coefficient was evaluated using the guidelines suggested by George and Mallery (2020) where > 0.9 excellent, > 0.8 good, > 0.7 acceptable, > 0.6 questionable, > 0.5 poor, and ≤ 0.5 unacceptable. The items for the questionnaire had a Cronbach's alpha coefficient of 0.85, indicating good reliability. Table 3 presents the reliability analysis results for questionnaire items for students' perception of Using GeoGebra.

Table 3

Reliability Table for Questionnaire Items for Students' Perception of Using GeoGebra

Scale	No. of Items	α	Lower Bound	Upper Bound
Questionnaire	15	.85	.79	.92

Note. The lower and upper bounds of Cronbach's α were calculated using a 95.00% confidence interval.

Data Analysis

The Impacts of Using GeoGebra on Students' Achievement in Geometric Transformations

Research Question 1: To what extent does teaching through GeoGebra affect students' achievement in geometric transformations?

Null Hypothesis (H_0) 1: No statistically significant difference exists in the experimental and control groups' geometric transformations achievement test (Gained test score).

Alternative Hypothesis (H_1) 1: A statistically significant difference exists in the experimental and control groups' geometric transformations achievement test (Gained test score).

A Kruskal-Wallis test was conducted to examine the research question to determine if there was a significant difference in the geometric transformations achievement test (Gained test score) between the experimental and control groups. The Kruskal Wallis test is the non-parametric alternative to a one-way ANOVA (Conover & Iman, 1981). It is the appropriate statistical analysis when the purpose of research is to assess if a difference exists on one ordinal/continuous dependent variable by an independent variable with two or more discrete groups. Given the non-parametric nature of this statistical analysis, there are no assumptions. The Kruskal-Wallis rank sum test can be conducted when the assumptions of a one-way ANOVA (such as normality) are violated.

The Kruskal-Wallis test compares the number of times a score from one sample is ranked higher than those from others. The scores from both samples were ranked together; rank 1 is used for the lowest score, rank 2 for the next lowest score, and so on. When scores have the same value, a tie is determined. Each of the tied scores is then assigned the same ranking. The scores are ranked, and those ranks are added together and then divided by the number of scores. Once the data was ranked, calculations were carried out on the ranks to calculate the chi-squared (χ^2) test statistic, which was used to compute a *p*-value. A significance level of 0.05 was used to determine if there are significant differences in the dependent variable between the independent variable levels. I also analyzed the geometric transformations achievement test item by item, difficulty levels, and categories to provide detailed information for the first question.

Students' Perceptions of Using GeoGebra and Their Achievement in Learning Geometric Transformations

Research Question 2: What is the relationship between students' perceptions of using GeoGebra and their geometric transformations achievement test?

Null Hypothesis (H_0) 2: No statistically significant relationship exists between students' perceptions of using GeoGebra and their geometric transformations achievement test.

Alternative Hypothesis (H_1) 2: A statistically significant relationship exists between students' perceptions of using GeoGebra and their geometric transformations achievement test.

A Spearman rank correlation was conducted to examine the research question to assess if a relationship exists between students' perceptions of using GeoGebra and students' geometric transformations achievement test. A Spearman rank correlation is the appropriate analysis when one or both variables are ordinal, but it can be used with scale variables. The correlation is a bivariate measure of association (or strength) of the relationship between two variables and the magnitude of that relationship. The Spearman rank correlation assumes that the variables have a monotonic relationship (Conover & Iman, 1981). A monotonic association means that the relationship between the variables does not change direction. This assumption was violated if the relationship between the variables shifts from positive to negative or vice versa. The assumption of monotonicity was assessed graphically with a scatterplot.

Correlation coefficients, r_s, vary from 0 (no relationship) to 1 (perfect linear relationship) or -1 (perfect negative linear relationship). Positive coefficients indicate a direct relationship, indicating that as one variable increases, the other variable also increases. Negative correlation coefficients indicate an indirect relationship, indicating that as one variable increases, the other variable decreases. Cohen's standard was used to evaluate the correlation coefficient, where 0.10 to 0.29 represents a weak association between the two variables, 0.30 to 0.49 represents a moderate association, and 0.50 or larger represents a strong association (Cohen, 1988). I also analyzed the students' perceptions of using the GeoGebra questionnaire item by item to provide detailed information for the second question.

Students' Perceptions of Using GeoGebra in Learning Geometric Transformations

Research Question 3: What are student perceptions about using GeoGebra in learning geometric transformations?

Null Hypothesis (H_0) 3: Students generally provided negative feedback about using GeoGebra in learning geometric transformations.

Alternative Hypothesis (H_1) 3: Students generally provided positive feedback about using GeoGebra in learning geometric transformations.

The first five questionnaire items were about general information; the rest was related to perceptions of using GeoGebra. Descriptive statistics were used to analyze the overall questionnaire results. Frequencies and percentages were calculated for Item 6, Item 7, Item 8, Item 9, Item 10, Item 11, Item 12, Item 13, Item 14, Item 15, Item 16, Item 17, Item 18, Item 19, and Item 20 to analyze students' perceptions of using GeoGebra in learning geometric transformations**.** I also identified students' perceptions of using GeoGebra between the factor levels of the demographic characteristics and item analysis by category to provide detailed information for the third question.

Summary

The chapter presented the research design, data collection method, and data analysis method related to students' achievement in geometric transformations and their perceptions of using GeoGebra. The chapter also provided detailed information about designing a quantitative research method and analyzing the research data using a statistical tool. A Kruskal-Wallis test was conducted to examine the research question to determine if the groups significantly differed in the geometric transformations achievement test. A Spearman rank correlation was conducted to investigate the research question to assess if a relationship exists between students' perceptions of using GeoGebra and students' geometric transformations achievement test. This study also used descriptive statistics to analyze the students' perceptions of using GeoGebra in learning geometric transformations.

CHAPTER IV

RESULTS

This study used nonequivalent control groups and a correlational research design to examine the impacts of using GeoGebra on student achievement in learning geometric transformations and the effects of using GeoGebra on students' perceptions in learning geometric transformations. The analysis of the data was organized in accordance with the research questions. The experimental group was taught with GeoGebra, and the control group was taught without GeoGebra. There were two groups in the study: Teaching geometric transformations without GeoGebra was the control group, and teaching geometric transformations with GeoGebra was the experimental group. The Statistical Package for Social Sciences (SPSS, version 27) was used to calculate tests at a significance level of 0.05.

Kruskal Wallis, Spearman correlation, and descriptive statistics were used to answer the research questions. The sample size for the Kruskal Wallis test is the same as with the One-way ANOVA but with the same samples. Power analysis for a Kruskal Wallis test indicated the minimum required sample size to yield a statistical power of at least 0.8 with an alpha of 0.05 and a large expected effect size ($f = 0.40$) is 52. Power analysis for a two-tailed Spearman correlation test indicated that the minimum sample size to yield a statistical power of at least .8 with an alpha of 0.05 and a large effect size (p = 0.5) is 33. The minimum required sample size for this study is 52.

A chi-square goodness-of-fit test was conducted to assess whether observed frequencies differ from expected frequencies for the given control and experimental groups. Model significance was determined by calculating the chi-square coefficient ($\chi 2$). A p-value was obtained using a &chi[2] distribution with n - 1 degree of freedom, where n is the sample size. An alpha of 0.05 was used to determine statistical significance. A Chi-square goodness of fit test was conducted to examine whether the group was equally distributed across all categories. There were two levels in the group: experimental and control. The results of the test were not significant based on an alpha value of .05, $\chi^2(1) = 0.01$, $p = .930$. Since the test was not significant, the differences between observed and expected frequencies were not significantly different for the experimental and control groups. Table 4 presents the results of the Chi-Square goodness of fit test.

Table 4

Chi-Square Goodness of Fit Test for Group

Level	Observed Frequency	Expected Frequency
Control	65	65.50
Experimental	66	65.50

Note. $\chi^2(1) = 0.01$, $p = .930$.

The Impacts of Using GeoGebra on Students' Achievement in Geometric Transformations

Research Question 1: To what extent does teaching through GeoGebra affect students' achievement in geometric transformations?

Null Hypothesis (H_0) 1: No statistically significant difference exists in the experimental and control groups' geometric transformations achievement test (Gained test score).

Alternative Hypothesis (H_1) 1: A statistically significant difference exists in the experimental and control groups' geometric transformations achievement test (Gained test score).

A Kruskal-Wallis rank test was conducted to assess if there were significant differences in pretest scores between the levels of the group. The Kruskal-Wallis test is a non-parametric alternative to the one-way ANOVA and does not share the ANOVA's distributional assumptions (Conover & Iman, 1981).

The results of the Kruskal-Wallis test were not significant based on an alpha value of .05, $\chi^2(1) = 0.50$, $p = .481$, indicating the mean rank of the pretest score was similar for each level of the group. Table 5 presents the results of the Kruskal-Wallis rank sum test.

Table 5

Kruskal-Wallis Rank Sum Test for Pretest Score by Group

Level	Mean Rank	χ^2	*df*	*p*
Experimental	63.68	0.50	1	.481
Control	68.35			

The results of the Kruskal-Wallis test were not significant based on an alpha value of .05, $\chi^2(1) = 0.50$, $p = .481$, indicating the mean rank of the pretest score was similar in the control and experimental groups.

The gained test score of the geometric transformations achievement test was used to calculate the differences between geometric transformations achievement posttest and geometric transformations achievement pretest.

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in gained test scores between the levels of the group. The results of the Kruskal-

Wallis test were significant based on an alpha value of .05, $\chi^2(1) = 11.75$, $p < .001$, indicating the mean rank of gained test score was significantly different between the levels of the group. Table 6 presents the results of the Kruskal-Wallis rank sum test.

Table 6

Kruskal-Wallis Rank Sum Test for Gained Test Score by Group

Level	Mean Rank	χ^2	*df*	*p*
Experimental	77.27	11.75	1	< .001
Control	54.55			

Post-hoc

Pairwise comparisons were examined between each level of the group. The results of the multiple comparisons indicated significant differences based on an alpha value of .05 between Experimental-Control. Table 7 presents the results of the pairwise comparisons.

Table 7

Pairwise Comparisons for the Mean Ranks of Gained Test Score by Levels of Group

Comparison	Observed Difference	Critical Difference
Experimental-Control	22.72	13.00

Note. Observed Differences > Critical Differences indicate significance at the $p < 0.05$ level.

Geometric Transformation Achievement Test Item Analysis

I analyzed the geometric transformations achievement test item by item, difficulty levels, and categories to provide detailed information for the first question.

Item by Item Analysis. A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in posttest questions between the levels of the group. Table 8 presents the results of the Kruskal-Wallis rank sum test for posttest questions 1-20 by the group.

Table 8

Kruskal-Wallis Rank Sum Test for Posttest Question 1-20 by Group

Question	Experimental	Control
	Mean Rank	
Question 1	68.08	63.88
Question 2	78.11	53.70
Question 3	69.20	62.75
Question 4	60.17	71.92
Question 5	70.08	61.86
Question 6	67.61	64.36
Question 7	68.62	63.34
Question 8	66.11	65.88
Question 9	68.19	63.78
Question 10	69.17	62.78
Question 11	63.59	68.45
Question 12	70.62	61.31
Question 13	70.71	61.22
Question 14	74.65	57.22
Question 15	67.11	64.88
Question 16	67.20	64.78
Question 17	70.73	61.20
Question 18	65.08	66.94
Question 19	69.17	62.78
Question 20	67.70	64.28

The results of the Kruskal-Wallis test were reported if there were significant differences in posttest questions 1-20 between the levels of the group. The results of the Kruskal-Wallis test were significant based on an alpha value of .05, $\chi^2(1) = 18.63$, $p < .001$, indicating the mean rank of posttest question 2 was significantly different between the levels of the group. Table 9 presents the results of the Kruskal-Wallis rank sum test.

Table 9

Kruskal-Wallis Rank Sum Test for Posttest Question 2 by Group

Level	Mean Rank	χ^2	*df*	*p*
Experimental	78.11	18.63	1	< .001
Control	53.70			

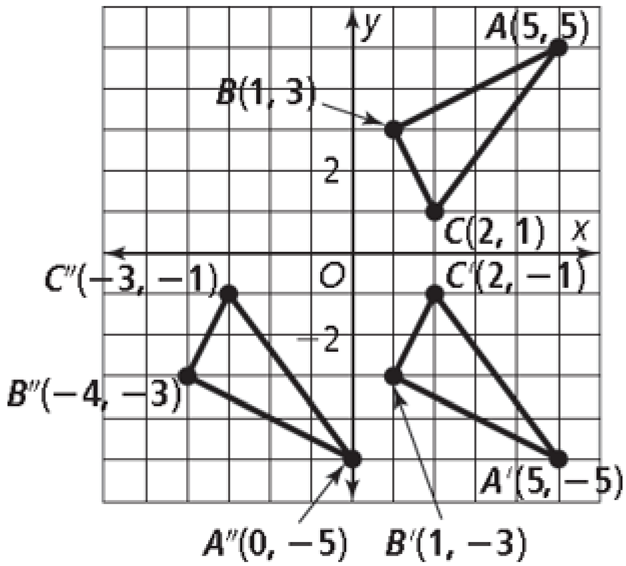
Post-hoc. Pairwise comparisons were examined between each level of the group. The results of the multiple comparisons indicated significant differences based on an alpha value of .05 between experimental and control. Table 10 presents the results of the pairwise comparisons for the mean ranks of posttest question 2 by levels of group. Figure 3 presents posttest question 2.

Table 10

Pairwise Comparisons for the Mean Ranks of Posttest Question 2 by Levels of Group

Comparison	Observed Difference	Critical Difference
Experimental-Control	24.41	13.00

2. Which of the descriptions is true for the graph?



A. $\triangle A'B'C'$ is $T_{(0,-2)}$ ($\triangle ABC$)

B. $\triangle A'B'C'$ is ($T_{(0,-2)} \circ R_{x\text{-axis}}$) ($\triangle ABC$)

C. $\triangle A'B'C'$ is $R_{x\text{-axis}}$($\triangle ABC$)

D. $\triangle A'B'C'$ is $r_{90°}$($\triangle ABC$)

Figure 3: Posttest Question 2

The results of the Kruskal-Wallis test were significant based on an alpha value of .05, $\chi^2(1) = 9.37$, $p = .002$, indicating the mean rank of posttest question 14 was significantly different between the levels of the group. Table 11 presents the results of the Kruskal-Wallis rank sum test.

Table 11

Kruskal-Wallis Rank Sum Test for Posttest Question 14 by Group

Level	Mean Rank	χ^2	*df*	*p*
Experimental	74.65	9.37	1	.002
Control	57.22			

Post-hoc. Pairwise comparisons were examined between each level of the group. The results of the multiple comparisons indicated significant differences based on an alpha value of .05 between experimental and control. Table 12 presents the results of the pairwise comparisons. Figure 4 represents posttest question 14. Figure 4 presents posttest question 14.

Table 12

Pairwise Comparisons for the Mean Ranks of Posttest Question 14 by Levels of Group

Comparison	Observed Difference	Critical Difference
Experimental-Control	17.44	13.00

Note. Observed Differences > Critical Differences indicate significance at the $p < 0.05$ level.

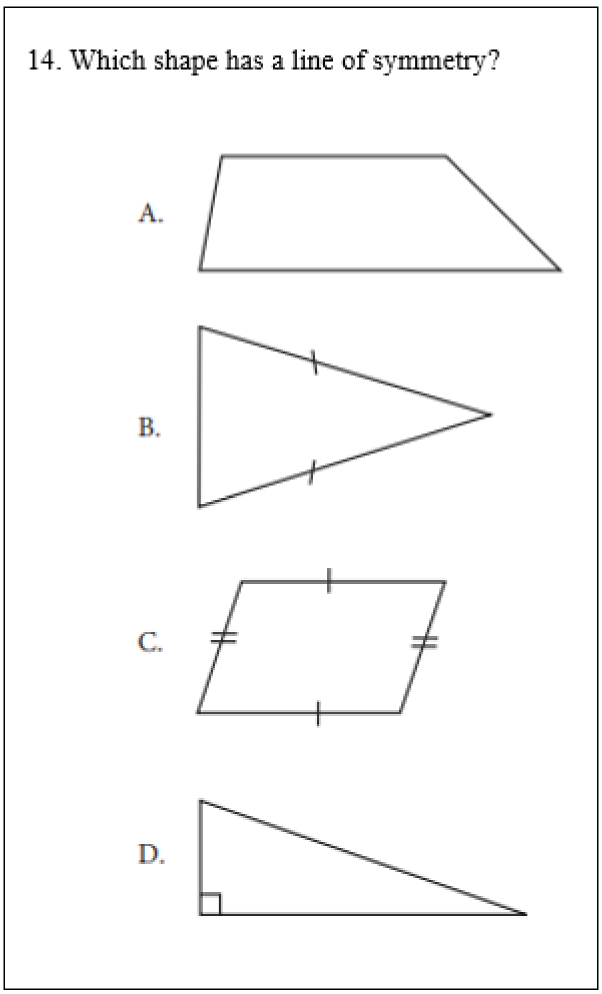


Figure 4: Posttest Question 14

Item Analysis by Category

A Kruskal-Wallis rank-sum test was conducted to assess if there were significant differences in Category 1: Rigid-Motion Transformations (Questions: 1, 5, 10, 17), Category 2: Rotation (Questions: 3, 11, 13, 20), Category 3: Reflection (Questions: 2, 12, 15, 19), Category 4: Translation (Questions: 6, 8, 16, 18), and Category 5: Symmetry (Questions: 4, 7, 9, 14) between the levels of Group. The results of the Kruskal-Wallis test were reported if there were significant differences in the category between the levels of Category 1: Rigid-Motion Transformations, Category 2: Rotation, Category 3: Reflection, Category 4: Translation, and Category 5: Symmetry. Table 13 presents the results of the Kruskal-Wallis Rank Sum Test for posttest Category 1-5 by the group.

Table 13

Kruskal-Wallis Rank Sum Test for Posttest Category *1-5 by Group*

Category	Description of Category	Experimental	Control
		Mean Rank	
Category 1	Rigid-Motion Transformations	73.19	58.70
Category 2	Rotation	70.89	61.04
Category 3	Reflection	70.71	61.22
Category 4	Translation	68.48	63.48
Category 5	Symmetry	66.90	65.08

The results of the Kruskal-Wallis test were significant based on an alpha value of .05, $\chi^2(1) = 5.19$, $p = .023$, indicating the mean rank of Category 1: Rigid-Motion Transformations was significantly different between the levels of the group. Table 14 presents the results of the Kruskal-Wallis rank sum test.

Table 14

Kruskal-Wallis Rank Sum Test for Category 1: Rigid-Motion Transformations by Group

Level	Mean Rank	χ^2	*df*	*p*
Experimental	73.19	5.19	1	.023
Control	58.70			

Post-hoc. Pairwise comparisons were examined between each level of the group. The results of the multiple comparisons indicated significant differences based on an alpha value of .05 between experimental and control. Table 15 presents the results of the pairwise comparisons. Figure 5 represents the sample question for category 1: rigid-motion transformations.

Table 15

Pairwise Comparisons for the Mean Ranks of Category 1: Rigid-Motion Transformations by Levels of Group

Comparison	Observed Difference	Critical Difference
Experimental-Control	14.49	13.00

Note. Observed Differences > Critical Differences indicate significance at the $p < 0.05$ level.

1. Which of these transformations, taken in order, can be used so that Figure 1 above becomes Figure 2 and then Figure 3?

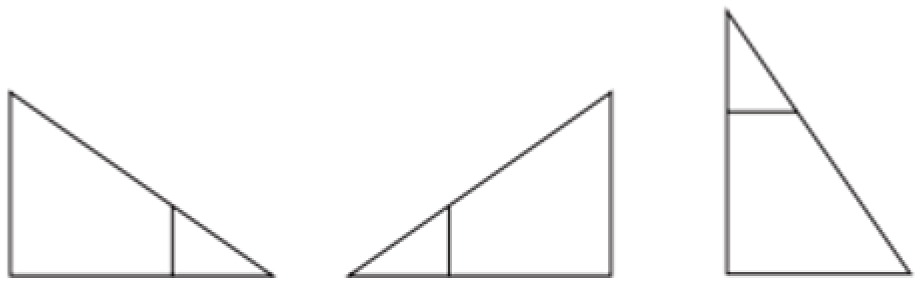


Figure 1 Figure 2 Figure 3

A. Reflection and then translation

B. Reflection and then $\frac{1}{4}$ turn rotation clockwise

C. $\frac{1}{2}$ turn rotation and then translation

D. $\frac{1}{4}$ turn rotation counterclockwise and then reflection

Figure 5: Sample Question for the Category 1: Rigid-Motion Transformations

Item Analysis by Difficulty Level

A Kruskal-Wallis rank-sum test was conducted to assess if there were significant differences in Easy (Level 1): Recall and Reproduction (Questions: 15, 18), Medium (Level 2): Skills/Concept (Questions: 3, 4, 6, 7, 8, 9, 11, 12, 14, 16), and Hard (Level 3): Strategic Thinking (Questions: 1, 2, 5, 10, 13, 17, 19, 20) between the levels of the group. The results of the Kruskal-Wallis test were reported if there were significant differences in difficulty levels between the levels of the group. Table 16 represents the results of the Kruskal-Wallis Rank sum test for posttest difficulty levels 1-3 by the group.

Table 16

Kruskal-Wallis Rank Sum Test for Posttest Difficulty Level 1-3 by Group

Difficulty Level	Description of Category	Experimental	Control
		Mean Rank	
Easy (Level 1)	Recall and Reproduction	67.72	64.25
Medium (Level 2)	Skills/Concept	70.86	61.06
Hard (Level 3)	Strategic Thinking	76.23	55.62

The results of the Kruskal-Wallis test were significant based on an alpha value of .05, $\chi^2(1) = 9.94$, $p = .002$, indicating the mean rank of hard level 3 was significantly different between the levels of the group. Table 17 presents the results of the Kruskal-Wallis rank sum test.

Table 17

Kruskal-Wallis Rank Sum Test for Hard Level 3 by Group

Level	Mean Rank	χ^2	*df*	*p*
Experimental	76.23	9.94	1	.002
Control	55.62			

Post-hoc. Pairwise comparisons were examined between each level of the group. The results of the multiple comparisons indicated significant differences based on an alpha value of .05 between experimental and control. Table 18 presents the results of the pairwise comparisons. Figure 5 represents the sample question for the hard level 3. Figure 6 represents the sample question for the hard level 3.

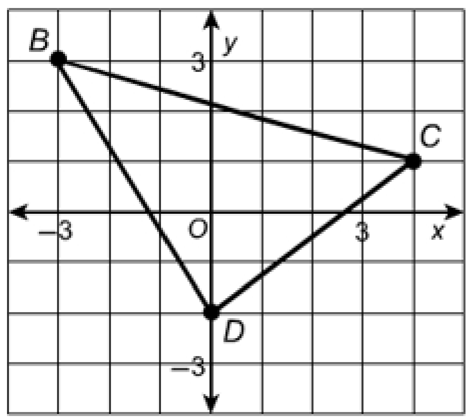
Table 18

Pairwise Comparisons for the Mean Ranks of Hard Level 3 by Levels of Group

Comparison	Observed Difference	Critical Difference
Experimental-Control	20.61	13.00

Note. Observed Differences > Critical Differences indicate significance at the $p < 0.05$ level.

13. Use △BCD in the figure shown. What are the vertices of the image after the triangle is rotated 90° clockwise about the origin?



A. B' (−3, −3), C' (−1, 4), D' (2, 0)

B. B' (3, −3), C' (1, 4), D' (0, 2)

C. B' (3, 3), C' (1, −4), D' (−2, 0)

D. B' (−3, −3), C' (−1, −4), D' (0, −2)

Figure 6: Sample Question for Hard Level 3

The Correlation on Geometric Transformation Achievement Test Item Analysis

A Spearman correlation analysis was conducted among posttest Q1- Q20. Cohen's standard was used to evaluate the strength of the relationships, where coefficients between .10

and .29 represent a small effect size, coefficients between .30 and .49 represent a moderate effect size, and coefficients above .50 indicate a large effect size (Cohen, 1988).

Monotonic Relationship. A Spearman correlation requires that the relationship between each pair of variables does not change direction (Conover & Iman, 1981). This assumption is violated if the points on the scatterplot between any pair of variables appear to shift from a positive to negative or negative to positive relationship. The result of the correlations was examined using the Holm correction to adjust for multiple comparisons based on an alpha value of .05. A significant positive correlation was reported between Posttest Questions. Table 19 represents spearman correlation results for PostQ1-PostQ20.

Table 19

Spearman Correlation Results for PostQ1-PostQ20

Combination	*r*	95.00% CI	*n*	*p*
PostQ1-PostQ14	.37	[.22, .51]	131	< .002
PostQ3-PostQ16	.35	[.19, .49]	131	< .009
PostQ5-PostQ12	.37	[.21, .51]	131	< .002
PostQ6-PostQ10	.41	[.26, .55]	131	< .001
PostQ6-PostQ12	.37	[.34, .60]	131	< .001
PostQ6-PostQ17	.34	[.18, .48]	131	< .013
PostQ7-PostQ11	.37	[.21, .51]	131	< .003
PostQ7-PostQ19	.36	[.20, .50]	131	< .005
PostQ10-PostQ12	.36	[.27, .55]	131	< .001
PostQ10-PostQ12	.42	[.27, .55]	131	< .001
PostQ12-PostQ17	.41	[.26, .54]	131	< .001
PostQ12-PostQ19	.36	[.20, .50]	131	< .001
PostQ13-PostQ17	.42	[.27, .55]	131	< .001
PostQ14-PostQ15	.40	[.25, .54]	131	< .001
PostQ16-PostQ19	.49	[.35, .61]	131	< .001
PostQ13-PostQ17	.42	[.27, .55]	131	< .001

The highest significant positive correlation was observed between Posttest Q16 and Posttest Q19, with a correlation of .49. A Spearman correlation analysis was conducted between PostQ16 and PostQ19. Figure 7 presents the scatterplot of the correlation. A regression line has been added to assist the interpretation. Table 20 presents the results of the correlation.

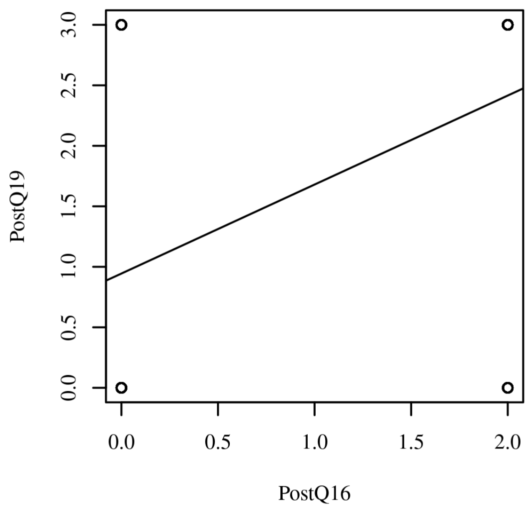


Figure 7: Scatterplots with the regression line added for PostQ16 and PostQ19

Table 20

Spearman Correlation Results Between PostQ16 and PostQ19

Combination	*r*	95.00% CI	*n*	*p*
PostQ16-PostQ19	.49	[.35, .61]	131	< .001

Students' Perceptions of Using GeoGebra and Their Achievement in Learning Geometric Transformations

Research Question 2: What is the relationship between students' perceptions of using GeoGebra and their geometric transformations achievement test?

Null Hypothesis (H_0) 2: No statistically significant relationship exists between students' perceptions of using GeoGebra and their geometric transformations achievement test.

Alternative Hypothesis (H_1) 2: A statistically significant relationship exists between students' perceptions of using GeoGebra and their geometric transformations achievement test.

A Spearman correlation analysis was conducted between students' perceptions of using GeoGebra and their geometric transformations achievement test. Figure 8 presents the scatterplot of the correlation. A regression line has been added to assist the interpretation.

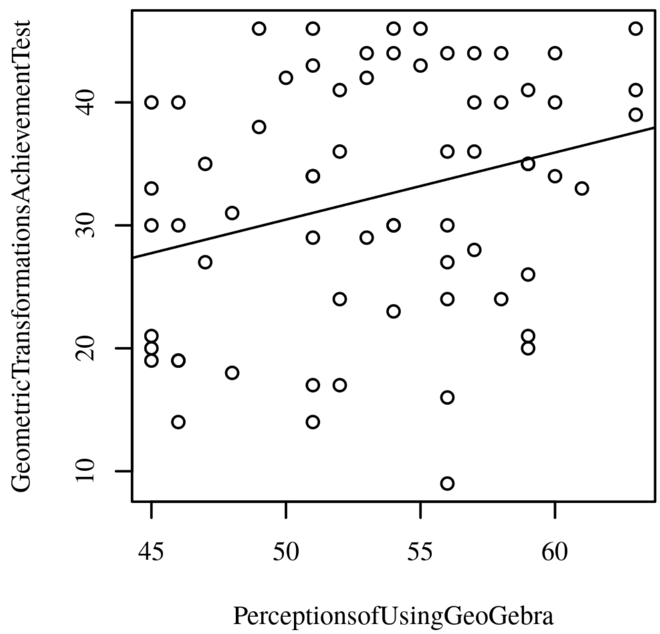


Figure 8: Scatterplots with the regression line added for Perceptions of Using GeoGebra and Geometric Transformations Achievement Test

The result of the correlation was examined based on an alpha value of .05. A significant positive correlation was observed between perceptions of using GeoGebra and geometric transformations achievement test, with a correlation of .26, indicating a small effect size (p = .033, 95.00% CI = [.02, .47]). This suggests that as perceptions of using GeoGebra increase, the geometric transformations achievement test tends to increase. Table 21 presents the results of the correlation.

Table 21

Spearman Correlation Results Between Students' Perceptions of Using GeoGebra and Students' Geometric Transformations Achievement Test

Combination	*r*	95.00% CI	*n*	*p*
Students' Perceptions of Using GeoGebra - Students' Geometric Transformations Achievement Test	.26	[.02, .47]	66	.033

The Correlation on Students' Perceptions of Using GeoGebra Item Analysis

I analyzed the students' perceptions of using the GeoGebra questionnaire Item by item correlation analysis to provide detailed information for the second question.

Item by Item Correlation Analysis. A Spearman correlation analysis was conducted among Item 6- Item 20. A significant correlation was reported between the students' perceptions of using GeoGebra items. Table 22 represents spearman correlation results Item 6-Item 22.

Table 22

Spearman Correlation Results Item 6-Item 20

Combination	*r*	95.00% CI	*n*	*p*
Item 6-Item 10	.48	[.27, .65]	66	< .004
Item 7-Item 9	.43	[.21, .61]	66	< .028
Item 7-Item 14	.43	[.21, .61]	66	< .024
Item 8-Item 19	.41	[.19, .60]	66	< .047
Item 9-Item 10	.54	[.35, .69]	66	< .001
Item 9-Item 11	.44	[.22, .62]	66	< .021
Item 9-Item 13	.53	[.33, .68]	66	< .001
Item 9-Item 14	.54	[.34, .69]	66	< .001
Item 9-Item 16	.51	[.31, .67]	66	< .001
Item 9-Item 18	.46	[.25, .63]	66	< .009
Item 9-Item 19	.54	[.35, .69]	66	< .001
Item 10-Item 18	.51	[.31, .67]	66	< .001
Item 11-Item 13	.50	[.30, .66]	66	< .002
Item 11-Item 18	.47	[.25, .64]	66	< .008
Item 11-Item 20	-.44	[-.62, -.22]	66	< .020
Item 13-Item 14	.45	[.24, .63]	66	< .013
Item 14-Item 19	.52	[.31, .67]	66	< .001
Item 17-Item 18	.44	[.22, .62]	66	< .019
Item 18-Item 20	-.61	[-.74, -.43]	66	< .001

The highest significant positive correlation was observed between Item 9 and Item 10, Item 9 and Item 14, and Item 9 and Item 19, with a correlation of .54, indicating a large effect size. A Spearman correlation analysis was conducted between I9 and I10. Figure 9 presents the scatterplot of the correlation. A regression line has been added to assist the interpretation. Table 23 presents the results of the correlation.

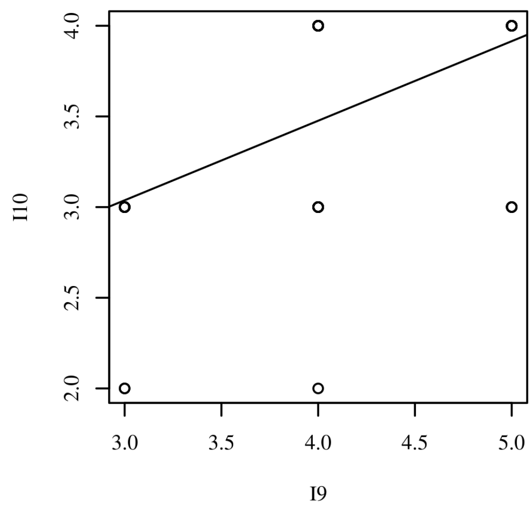


Figure 9: Scatterplots with the regression line added for I9 and I10

Table 23

Spearman Correlation Results Between I9 and I10

Combination	*r*	95.00% CI	*n*	*p*
I9-I10	.54	[.35, .69]	66	< .001

A Spearman correlation analysis was conducted between I9 and I14. Figure 10 presents the scatterplot of the correlation. A regression line has been added to assist the interpretation. Table 24 presents the results of the correlation.

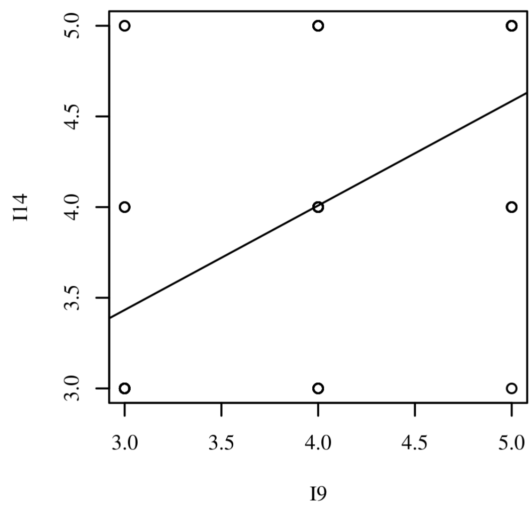


Figure 10: Scatterplots with the regression line added for I9 and I14

Table 24

Spearman Correlation Results Between I9 and I14

Combination	*r*	95.00% CI	*n*	*p*
I9-I14	.54	[.34, .69]	66	< .001

A Spearman correlation analysis was conducted between I9 and I19. Figure 11 presents the scatterplot of the correlation. A regression line has been added to assist the interpretation. Table 25 presents the results of the correlation.

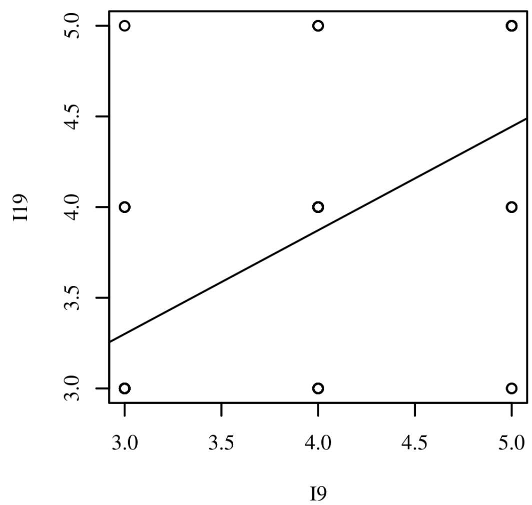


Figure 11: Scatterplots with the regression line added for I9 and I19

Table 25

Spearman Correlation Results Between I9 and I19

Combination	*r*	95.00% CI	*n*	*p*
I9-I19	.54	[.35, .69]	66	< .001

Also, a significant negative correlation was observed between Item 18 and Item 20, with a correlation of -.61, indicating a large effect size (p < .001, 95.00% CI = [-.74, -.43]). This suggests that as Item 18 increases, Item 20 tends to decrease. A Spearman correlation analysis was conducted between I18 and I20. Figure 12 presents the scatterplot of the correlation. A regression line has been added to assist the interpretation. Table 26 presents the results of the correlation.

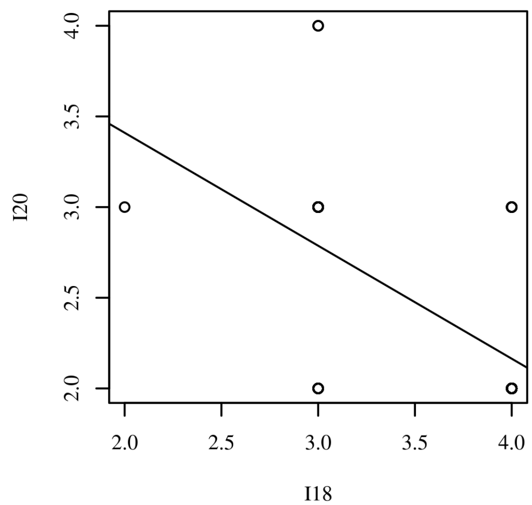


Figure 12: Scatterplots with the regression line added for I18 and I20

Table 26

Spearman Correlation Results Between I18 and I20

Combination	*r*	95.00% CI	*n*	*p*
I18-I20	-.61	[-.74, -.43]	66	< .001

Students' Perceptions of Using GeoGebra in Learning Geometric Transformations

Research Question 3: What are student perceptions about using GeoGebra in learning geometric transformations?

Null Hypothesis (H_0) 3: Students generally provided negative feedback about using GeoGebra in learning geometric transformations.

Alternative Hypothesis (H_1) 3: Students generally provided positive feedback about using GeoGebra in learning geometric transformations.

After completing the experiment, students' perception of using GeoGebra in learning geometric transformations was measured using a questionnaire consisting of 15 items. Only the experimental group took students' perceptions of using the GeoGebra questionnaire. All items were in the form of a Likert scale from Strongly Disagree to Strongly Agree. The scoring technique is 1 for Strongly Disagree, 5 for Strongly Agree for positive items, and reverse scoring for negative items. This study used descriptive statistics and percentages for the students' perceptions of using GeoGebra in learning geometric transformations. When the skewness is greater than 2 in absolute value, the variable is considered to be asymmetrical about its mean. When the kurtosis is greater than or equal to 3, the variable's distribution is markedly different from a normal distribution in its tendency to produce outliers (Westfall & Henning, 2013). The descriptive statistics can be found in Table 27.

Table 27

Descriptive Statistics Table for Interval and Ratio Variables

Variable	*M*	*SD*	*n*	SE_M	Min	Max	Skewness	Kurtosis
Item 6	3.41	0.61	66	0.07	2.00	4.00	-0.48	-0.65
Item 7	3.80	0.66	66	0.08	3.00	5.00	0.23	-0.74
Item 8	3.27	0.78	66	0.10	1.00	4.00	-1.11	1.26
Item 9	3.98	0.71	66	0.09	3.00	5.00	0.02	-1.00
Item 10	3.47	0.59	66	0.07	2.00	4.00	-0.57	-0.63
Item 11	3.68	0.73	66	0.09	3.00	5.00	0.56	-0.92
Item 12	3.67	0.48	66	0.06	3.00	4.00	-0.71	-1.50
Item 13	3.42	0.58	66	0.07	2.00	4.00	-0.41	-0.74
Item 14	4.00	0.76	66	0.09	3.00	5.00	0.00	-1.26
Item 15	3.36	0.57	66	0.07	2.00	4.00	-0.20	-0.75
Item 16	3.92	0.71	66	0.09	3.00	5.00	0.11	-0.98
Item 17	3.50	0.69	66	0.08	1.00	4.00	-1.30	1.48
Item 18	3.48	0.53	66	0.07	2.00	4.00	-0.25	-1.27
Item 19	3.86	0.74	66	0.09	3.00	5.00	0.22	-1.14
Item 20	2.48	0.56	66	0.07	2.00	4.00	0.59	-0.72

Note. '-' indicates the statistic is undefined due to constant data or insufficient sample size.

I used a calculation to find the criterion means for students' perception of using GeoGebra. It was a 15-item questionnaire structured on a five-point Likert scale of 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, and 5-Strongly Agree. The scoring technique was used 1 for Strongly Disagree, 2 for Disagree, 3 for Neutral, 4 for Agree, 5 for Strongly Agree for positive items, and reversed scoring in negative items. Item 14 is a negative item, so the score has been reversed. The observations for Item 14 had the highest average of 4.00. The results indicated that GeoGebra is friendly to use in learning geometric transformations. Figure 13 represents students' perceptions of using GeoGebra Item 14.

14. GeoGebra is not friendly to use in learning geometric transformations.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

Figure 13: Students' Perceptions of Using GeoGebra Item 14

The frequencies and percentages were calculated for Item 6, Item 7, Item 8, Item 9, Item 10, Item 11, Item 12, Item 13, Item 14, Item 15, Item 16, Item 17, Item 18, Item 19, and Item 20. Table 28 represents the frequency table for nominal variables.

Table 28

Frequency Table for Nominal Variables

Variable	Strongly Disagree		Disagree		Neutral		Agree		Strongly Agree	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Item 6	0	0.00	4	6.06	31	46.97	31	46.97	0	0.00
Item 7	0	0.00	0	0.00	22	33.33	35	53.03	9	13.64
Item 8	3	4.55	4	6.06	31	46.97	28	42.42	0	0.00
Item 9	0	0.00	0	0.00	17	25.76	33	50.00	16	24.24
Item 10	0	0.00	3	4.55	29	43.94	34	51.52	0	0.00
Item 11	0	0.00	0	0.00	31	46.97	25	37.88	10	15.15
Item 12	0	0.00	0	0.00	22	33.33	44	66.67	0	0.00
Item 13	0	0.00	3	4.55	32	48.48	31	46.97	0	0.00
Item 14	0	0.00	0	0.00	19	28.79	28	42.42	19	28.79
Item 15	0	0.00	3	4.55	36	54.55	27	40.91	0	0.00
Item 16	0	0.00	0	0.00	19	28.79	33	50.00	14	21.21
Item 17	1	1.52	4	6.06	22	33.33	39	59.09	0	0.00
Item 18	0	0.00	1	1.52	32	48.48	33	50.00	0	0.00
Item 19	0	0.00	0	0.00	23	34.85	29	43.94	14	21.21
Item 20	0	0.00	36	54.55	28	42.42	2	3.03	0	0.00

Note. Due to rounding errors, percentages may not equal 100%.

Students' Perceptions of Using GeoGebra in Learning Geometric Transformations Item Analysis

I identified students' perceptions of using GeoGebra between the factor levels of the demographic characteristics and item analysis by category to provide detailed information for the third question.

Students' Perceptions of Using GeoGebra by Demographic Characteristics Item Analysis

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in perceptions of using GeoGebra between the levels of gender. The results of the

Kruskal-Wallis test were not significant based on an alpha value of .05, $\chi^2(1) = 0.01$, $p = .908$, indicating the mean rank of perceptions of using GeoGebra was similar for each level of Gender. Table 29 presents the results of the Kruskal-Wallis rank sum test.

Table 29

Kruskal-Wallis Rank Sum Test for Perceptions of Using GeoGebra by Gender

Level	Mean Rank	χ^2	*df*	*p*
Male	33.24	0.01	1	.908
Female	33.79			

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in perceptions of using GeoGebra between the levels of age. The results of the Kruskal-Wallis test were not significant based on an alpha value of .05, $\chi^2(3) = 5.74$, $p = .125$, indicating the mean rank of perceptions of using GeoGebra was similar for each level of age. Table 30 presents the results of the Kruskal-Wallis rank sum test.

Table 30

Kruskal-Wallis Rank Sum Test for Perceptions of Using GeoGebra by Age

Level	Mean Rank	χ^2	*df*	*p*
15 years old	30.42	5.74	3	.125
Under 15 years old	36.22			
16 years old	43.50			
Above 16 years old	8.00			

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in perceptions of using GeoGebra between the levels of ethnic background. The results of the Kruskal-Wallis test were not significant based on an alpha value of .05, $\chi^2(3) = 1.82$, $p = .611$, indicating the mean rank of perceptions of using GeoGebra was similar for each level of ethnic background. Table 31 presents the results of the Kruskal-Wallis rank sum test.

Table 31

Kruskal-Wallis Rank Sum Test for Perceptions of Using GeoGebra by Ethnic Background

Level	Mean Rank	χ^2	*df*	*p*
Hispanic	31.86	1.82	3	.611
White	40.56			
Black or African American	38.60			
Asian	34.25			

Students' Perceptions of Using GeoGebra Item Analysis

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in questionnaire Item 6-20 between the levels of gender. The results of the Kruskal-Wallis test were reported if there were significant differences in questionnaire Item 6-20 between the levels of gender. Table 32 represents the Kruskal-Wallis Rank sum test results for the questionnaire (Item 6 – Item 20) by gender.

Table 32

Kruskal-Wallis Rank Sum Test for Questionnaire (Item 6 – Item 20) *by Gender*

Item	Male	Female
	Mean Rank	
Item 6	32.29	34.87
Item 7	36.63	29.97
Item 8	33.20	33.84
Item 9	34.57	32.29
Item 10	34.63	32.23
Item 11	35.00	31.81
Item 12	33.19	33.85
Item 13	32.90	34.18
Item 14	30.81	36.53
Item 15	35.34	31.42
Item 16	32.53	34.60
Item 17	32.31	34.84
Item 18	32.81	34.27
Item 19	28.93	38.66
Item 20	34.47	32.40

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in questionnaire Item 19 between the levels of gender. The results of the Kruskal-Wallis test were significant based on an alpha value of .05, $\chi^2(1) = 4.89$, $p = .027$, indicating that the mean rank of questionnaire Item 19 was significantly different between the levels of gender. Table 33 presents the results of the Kruskal-Wallis rank sum test.

Table 33

Kruskal-Wallis Rank Sum Test for Questionnaire Item 19 by Gender

Level	Mean Rank	χ^2	*df*	*p*
Male	28.93	4.89	1	.027
Female	38.66			

Post-hoc. Pairwise comparisons were examined between each level of gender. The results of the multiple comparisons indicated significant differences based on an alpha value of .05 between males and females. Table 34 presents the results of the pairwise comparisons.

Table 34

Pairwise Comparisons for the Mean Ranks of Questionnaire Item 19 by Levels of Gender

Comparison	Observed Difference	Critical Difference
Male-Female	9.73	9.28

Note. Observed Differences > Critical Differences indicate significance at the $p < 0.05$ level.

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in questionnaire Items 6-20 between the levels of age. The results of the Kruskal-Wallis test were reported if there were significant differences in questionnaire Items 6-20 between the levels of age. Table 35 represents the Kruskal-Wallis rank sum test for the questionnaire (Item 6 – Item 20) by age.

Table 35

Kruskal-Wallis Rank Sum Test for Questionnaire (Item 6 – Item 20) *by Age*

Questionnaire Item	15 years old	Under 15 years old	16 years old	Above 16 years old
		Mean Rank		
Item 6	35.42	32.32	40.67	20.00
Item 7	32.38	35.75	30.50	11.50
Item 8	30.06	34.89	52.50	23.00
Item 9	30.92	36.61	34.00	9.00
Item 10	30.58	35.06	49.50	18.00
Item 11	33.08	35.44	25.33	16.00
Item 12	33.94	35.33	22.50	11.50
Item 13	35.18	32.53	40.50	19.50
Item 14	29.74	36.76	41.33	10.00
Item 15	32.54	34.08	42.50	21.50
Item 16	35.50	31.83	43.83	23.00
Item 17	33.84	33.08	36.83	31.75
Item 18	32.44	33.75	39.17	33.75
Item 19	28.10	38.19	36.50	12.00
Item 20	30.02	35.33	39.83	34.50

The results of the Kruskal-Wallis test were not significant, based on an alpha value of .05, indicating the mean rank of questionnaire Items was not significantly different between the levels of age.

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in questionnaire Item 6-20 between the levels of ethnic background. The results of the Kruskal-Wallis test were reported if there were significant differences in questionnaire Item

6-20 between the levels of ethnic background. Table 36 represents the Kruskal-Wallis rank sum test for the questionnaire (Item 6 – Item 20) by ethnic background.

Table 36

Kruskal-Wallis Rank Sum Test for Questionnaire (Item 6 – Item 20) *by* Ethnic Background

Questionnaire Item	Hispanic	White	Black or African American	Asian
		Mean Rank		
Item 6	33.56	35.50	28.90	35.50
Item 7	32.53	39.19	33.00	36.75
Item 8	33.29	35.56	30.60	37.75
Item 9	31.47	46.19	33.80	33.75
Item 10	33.74	33.75	30.60	33.75
Item 11	32.68	37.88	36.30	33.75
Item 12	32.85	36.25	37.90	28.00
Item 13	33.02	37.00	32.10	35.25
Item 14	33.04	42.31	24.10	33.50
Item 15	31.47	45.12	34.10	37.25
Item 16	33.93	25.94	40.70	34.75
Item 17	32.52	31.75	47.00	31.75
Item 18	32.47	33.75	50.00	17.50
Item 19	32.62	33.63	41.40	35.75
Item 20	32.60	36.38	31.30	50.50

The results of the Kruskal-Wallis test were not significant, based on an alpha value of .05, indicating the mean rank of questionnaire Items was not significantly different between the levels of ethnic background.

Item Analysis by Category

A Kruskal-Wallis rank-sum test was conducted to assess if there were significant differences in geometry-related items (6, 8, 10, 11, 13), geometric transformations-related items (7, 9, 12, 14,15, 16, 17, 19), and curriculum-related items (18, 20) between the levels of gender, age, and ethnic background.

A Kruskal-Wallis rank-sum test was conducted to assess if there were significant differences in geometry-related items, geometric transformations-related items, and curriculum-related items between the levels of gender. The results of the Kruskal-Wallis test were reported if there were significant differences in geometry-related items, geometric transformations-related items, and curriculum-related items that were similar for each level of gender. Table 37 represents the Kruskal-Wallis Rank sum test for geometry, geometric transformations, and curriculum-related items by gender.

Table 37

Kruskal-Wallis Rank Sum Test for Geometry, Geometric Transformations, and Curriculum Related Items by Gender

Item	Male	Female
	Mean Rank	
Geometry Related	33.73	33.24
Geometric Transformations Related	32.89	34.19
Curriculum Related	33.57	33.42

The results of the Kruskal-Wallis test were not significant based on an alpha value of .05, indicating the mean rank of geometry-related items, geometric transformations-related items, and curriculum-related items were similar for each level of gender.

A Kruskal-Wallis rank-sum test was conducted to assess if there were significant differences in geometry-related items, geometric transformations-related items, and curriculum-related items between the levels of age. The results of the Kruskal-Wallis test were reported if there were significant differences in geometry-related items, geometric transformations-related items, and curriculum-related items that were similar for each level of age. Table 38 represents the Kruskal-Wallis rank sum test for geometry, geometric transformations, and curriculum-related items by age.

Table 38

Kruskal-Wallis Rank Sum Test for Geometry, Geometric Transformations, and Curriculum Related Items by Age

Item	15 years old	Under 15 years old	16 years old	Above 16 years old
		Mean Rank		
Geometry Related	31.72	34.93	46.17	11.00
Geometric Transformations Related	30.84	36.43	38.50	6.50
Curriculum Related	28.52	36.03	44.00	34.50

The results of the Kruskal-Wallis test were not significant based on an alpha value of .05, indicating the mean rank of geometry-related items, geometric transformations-related items, and curriculum-related items were similar for each level of age.

A Kruskal-Wallis rank-sum test was conducted to assess if there were significant differences in geometry-related items, geometric transformations-related items, and curriculum-related items between the levels of ethnic background. The results of the Kruskal-Wallis test were reported if there were significant differences in geometry-related items, geometric transformations-related items, and curriculum-related items that were similar for each level of ethnic background. Table 39 represents the Kruskal-Wallis rank sum test for geometry, geometric transformations, and curriculum-related items by ethnic background.

Table 39

Kruskal-Wallis Rank Sum Test for Geometry, Geometric Transformations, and Curriculum Related Items by Ethnic Background

Item	Hispanic	White	Black or African American	Asian
		Mean Rank		
Geometry Related	32.91	37.69	32.10	35.25
Geometric Transformations Related	32.00	40.38	37.20	35.00
Curriculum Related	31.53	38.06	45.90	34.50

The results of the Kruskal-Wallis test were not significant based on an alpha value of .05, indicating the mean rank of geometry-related items, geometric transformations-related items, and curriculum-related items were similar for each level of ethnic background.

Summary

This study's results showed a statistically significant difference in the control and experimental groups' geometric transformation achievement posttest. While the initial achievement of students on mathematics ability in the achievement of the geometric transformation pretest was similar in the control and experimental groups, overall geometric transformations achievement gained test scores in control, and experimental groups were significantly different, as calculated by the Kruskal-Wallis rank sum test. Students that received instruction using GeoGebra performed better than students that received instruction without using GeoGebra. Geometric transformation achievement test item analyses were conducted to provide more detailed information about students' achievement test results in geometric transformations. The first analysis was the item-by-item analysis that A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in posttest questions between the levels of the Group. The results of the Kruskal-Wallis test were significant based on an alpha value of .05, indicating the mean rank of posttest Questions 2 and 14 were significantly different between the levels of groups. The experimental group participants who used GeoGebra outperformed the control group who did not use GeoGebra in answering questions 2 and 14. Question 14 is related to symmetry, and question 2 is related to reflection. The results of the Kruskal-Wallis test were not significant, based on an alpha value of .05, indicating that the mean rank of other questions was similar for each level of the groups. The second analysis was Item analysis by category (Category 1: Rigid-Motion Transformations, Category 2: Rotation, Category 3: Reflection, Category 4: Translation, and Category 5: Symmetry). The results of the Kruskal-Wallis test were significant based on an alpha value of .05, indicating the mean rank of Category 1: Rigid-Motion Transformations was significantly different between the levels of Group. The results of the Kruskal-Wallis test were not significant, based on an alpha value of .05, indicating that the mean rank of other categories was similar for each level of the groups. The experimental group participants who used GeoGebra outperformed the control group who did not use GeoGebra in Category 1: Rigid-Motion Transformations. The third analysis was item analysis by difficulty level (easy (level 1): recall and reproduction, medium (level 2): skills/concept, and hard (level 3): strategic thinking). The results of the Kruskal-Wallis test were significant based on an alpha value of .05, indicating the mean rank of Hard Level 3 was significantly different between the levels of Group. The results of the Kruskal-Wallis test were not significant, based on an alpha value of .05, indicating that the mean rank of other difficulty levels was similar for each level of the groups. The experimental group participants who used GeoGebra outperformed the control group who did not use GeoGebra in hard (level 3). The experimental group participants who used GeoGebra outperformed the control group who did not use GeoGebra in answering hard-level questions. The fourth analysis was the correlation on geometric transformation achievement test item analysis. The highest significant positive correlation was observed between posttest Q16 and posttest Q19, with a correlation of .49, indicating a moderate effect size. This suggests that as Posttest Q16 increases, Posttest Q19 tends to increase.

A Spearman correlation analysis was conducted between students' perceptions of using GeoGebra and their geometric transformations achievement test, and a significant positive correlation was found between perceptions of using GeoGebra and the geometric transformations achievement test. A significant positive correlation was observed between perceptions of using GeoGebra and the geometric transformations achievement test, indicating a small effect size. The correlation on students' perceptions of using GeoGebra item analysis was conducted for detailed information. The first analysis was item by items correlation analysis. The highest significant positive correlation was observed between Item 9 and Item 10, Item 9 and Item 14, and Item 9 and Item 19, with a correlation of .54, indicating a large effect size.

Also, the descriptive statistics revealed that students' perceptions of using GeoGebra were positive. Students' perceptions of using GeoGebra item analyses were conducted to provide more detailed information. The first analysis was students' perceptions of using GeoGebra by demographic characteristics (gender, age, and ethnic background). A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in perceptions of using GeoGebra between the levels of demographic characteristics (gender, age, and ethnic background). The results of the Kruskal-Wallis test were not significant, based on an alpha value of .05, indicating the mean rank of perceptions of using GeoGebra was similar for each level of demographic characteristics (gender, age, and ethnic background). The second analysis was item-by-item analysis. A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in questionnaire items between the levels of gender, age, and ethnic background. The results of the Kruskal-Wallis test were significant based on an alpha value of .05, indicating that the mean rank of questionnaire item 19 was significantly different between the levels of gender. The results of the Kruskal-Wallis test were not significant, based on an alpha value of .05, indicating that the mean rank of other questions was similar for each level of gender. The results of the Kruskal-Wallis test were significant based on an alpha value of .05, indicating that the mean rank of Questionnaire Items was not significantly different between the levels of age and ethnic background. The third analysis was item analysis by category (geometry, geometric transformations, and curriculum-related items). A Kruskal-Wallis rank-sum test was conducted to assess if there were significant differences in geometry-related items, geometric transformations-related items, and curriculum-related items between the levels of gender, age, and ethnic background. The results of the Kruskal-Wallis test were not significant based on an alpha value of .05, indicating the mean rank of geometry-related items, geometric transformations-related items, and curriculum-related items were similar for each level of gender, age, and ethnic background.

CHAPTER V

SUMMARY AND CONCLUSION

This study examined the impacts of using GeoGebra on students' perceptions and achievement in learning geometric transformations. This study explored the impact of using GeoGebra in collaborative learning environments and the effect of using GeoGebra on students' perceptions and achievement in learning geometric transformations. I connected the results to the literature to answer the research questions.

Discussion

This study revealed that students who were taught using GeoGebra performed higher than students who were taught without using GeoGebra. The findings are supported by the reviewed literature. For instance, Seloraji and Eu (2017) conducted a study to determine whether GeoGebra improves students in geometric reflection. Seloraji and Eu's (2017) results showed that there is a significant difference in the mean scores in the experimental group taught with GeoGebra and in the control group taught without GeoGebra. It was concluded that GeoGebra improves student achievements in geometry.

Similarly, Shadaan and Eu (2013) examined the effectiveness of GeoGebra on student understanding of learning circles; 53 9^{th}-grade students participated in the study. The students were assigned to experimental and control groups. It was found that the experimental group of students who used GeoGebra performed better than the control group of students who did not use GeoGebra.

Likewise, Saha et al. (2010) examined the impact of GeoGebra on achievement in mathematics with a focus on learning coordinate geometry. The results confirmed that GeoGebra effectively improved students' learning of coordinate geometry. Reis and Ozdemir (2010) examined the effectiveness of GeoGebra on student achievement in learning the parabola in analytic geometry. The results confirmed that GeoGebra is an effective tool in understanding the parabola in analytic geometry. Khalil et al. (2018) conducted an instructive study of analytical geometry and the effectiveness of GeoGebra. The results showed that the experimental group achieved higher performance in analytical reasoning, generalization, abstract reasoning, representation, and logical reasoning than the control group.

The Impacts of Using GeoGebra on Students' Achievement in Geometric Transformations

Research Question 1: To what extent does teaching through GeoGebra affect students' achievement in geometric transformations?

Null Hypothesis (H_0) 1: No statistically significant difference exists in the experimental and control groups' geometric transformations achievement test (Gained test score).

Alternative Hypothesis (H_1) 1: A statistically significant difference exists in the experimental and control groups' geometric transformations achievement test (Gained test score).

The first research question explored how teaching through GeoGebra affected students' achievement in geometric transformations using the Kruskal-Wallis test. A summary of key findings followed by a discussion and the connections with recent research is included in the following sections.

The differences between observed and expected frequencies were not significantly different for the experimental and control groups at the beginning of the study. The experimental group (n = 66) and control group (n = 65) were equally distributed across all categories.

The students began with similar levels of mathematics ability, as evidenced by geometric transformation achievement pretest results. The results of the Kruskal-Wallis test were not significant, based on an alpha value of .05, indicating the mean rank of the pretest score was similar for each level of the group. This result supported that students began with similar levels of mathematics ability, as evidenced by geometric transformation achievement pretest results. A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in Gained test scores between the levels of the group. A statistically significant difference exists in the experimental and control groups' geometric transformations achievement posttest (Gained test score). The experimental group participants who used GeoGebra outperformed the control group who did not use GeoGebra. I concluded that there are statistically significant differences in students' achievement test scores between the experimental group who received instruction with GeoGebra and the control group who received instruction without GeoGebra in geometric transformations. Therefore, GeoGebra improved students' achievements in geometric transformations.

This finding aligned with that of Bwalya (2019), supported that the results showed that teaching using GeoGebra significantly affects students' achievement in geometric transformations. Interactive learning environments for geometry, such as GeoGebra, could significantly help to improve students' knowledge and understanding of mathematics, especially in challenging topics (Ganesan & Eu, 2020). Additionally, Singh (2018) examined the role of GeoGebra on student achievement in geometry. A quasi-experimental study was conducted with

23 students in an experimental group with GeoGebra, while 22 students were in a control group. The results showed that the experimental group performed better than the control group. From this, it was concluded that GeoGebra effectively contributes to improving learning geometry.

The finding indicated that the implication of GeoGebra in learning geometric transformations significantly affects students' achievement. Similar results were found by Bulut et al. (2016) in the effects of GeoGebra on third grade primary students' academic achievement in fractions; Zulnaidi & Zakaria (2012) in the effect of using GeoGebra on conceptual and procedural knowledge of high school mathematics students; Shadaan and Eu (2013) in effectiveness of using GeoGebra on students' understanding in learning circles; Tatar and Zengin (2016) in the conceptual understanding of definite integral with GeoGebra; Ibrahim and Ilyas (2016) in the teaching a concept with GeoGebra: Periodicity of trigonometric functions; Kushwaha et al. (2014) in the impact on students' achievement in teaching mathematics using GeoGebra; Arbain and Shukor (2015) in the effects of GeoGebra on student achievement; Zengin et al. (2012) in the effect of dynamic mathematics software GeoGebra on student achievement in teaching trigonometry; Emaikwu et al. (2015) in the effect of GeoGebra on senior secondary school students' interest and achievement in statistics in Makurdi local government area of Benue State; Khalil et al. (2018) in the development of mathematical achievement in the analytic geometry of grade-12 students through GeoGebra activities; Saha et al. (2010) in the effects of GeoGebra on mathematics achievement: Enlightening coordinate geometry learning; Ozcakir et al. (2015) in the effects of using dynamic geometry activities on eighth grade students' achievement levels and estimation performances in triangles; Tay (2018) in the effect of using GeoGebra on senior high school students' performance in circle theorems. The study's findings showed that GeoGebra is a valuable tool in learning geometry topics. The literature verified that GeoGebra is effective in learning geometry, and GeoGebra in learning geometric transformations affects students' achievement.

Students' Perceptions of Using GeoGebra and Their Achievement in Learning Geometric Transformations

Research Question 2: What is the relationship between students' perceptions of using GeoGebra and their geometric transformations achievement test?

Null Hypothesis (H_0) 2: No statistically significant relationship exists between students' perceptions of using GeoGebra and their geometric transformations achievement test.

Alternative Hypothesis (H_1) 2: A statistically significant relationship exists between students' perceptions of using GeoGebra and their geometric transformations achievement test.

The second research question explored the relationship between students' perceptions of using GeoGebra and their geometric transformations achievement test. A Spearman correlation analysis was conducted between students' perceptions of using GeoGebra and their geometric transformations achievement test. The result of the correlation was examined based on an alpha value of 0.05. A significant positive correlation was observed between students' perceptions of using GeoGebra and the geometric transformations achievement test, with a correlation of 0.26, indicating a small effect size. This suggests that as perceptions of using GeoGebra increase, the geometric transformations achievement test tends to increase. I concluded that a statistically significant relationship exists between students' perceptions of using GeoGebra and their geometric transformations achievement test.

This finding aligned with that of Ozdamli et al. (2013) conducted a study to determine the effect of technology-supported collaborative learning settings on students' perceptions of mathematics learning. The authors stated that students' perceptions of technology have increased after studying in technology-supported collaborative learning settings. Likewise, Zengin and Tatar (2017) used the open-ended questionnaire to get the students' perceptions of using GeoGebra and used an achievement test on quadratic functions. From the questionnaire, Zengin and Tatar (2017) concluded that GeoGebra helped promote better understanding by enabling students to visualize the course, which increased retention. Fifteen students stated in the questionnaire that GeoGebra helped them better understand mathematical concepts (Zengin & Tatar, 2017). Fourteen students stated that the GeoGebra helped them visualize the idea of quadratics functions and that the material was much more concrete (Zengin & Tatar, 2017). Zengin and Tatar (2017) conducted a study on the effect of cooperative learning supported with GeoGebra on student achievement in quadratic functions. The results showed that this integrated cooperative learning supported with GeoGebra increases student achievement in quadratic functions. This result is similar to previous research that examined cooperative learning use in mathematics classrooms (Tatar & Zengin, 2016; Thambi & Eu, 2013). Using GeoGebra effectively in a cooperative learning environment plays a significant role in acquiring one of the critical skills in the 21st century (Zengin & Tatar, 2016). Considering results about quadratic functions, the cooperative learning supported by GeoGebra significantly increased student achievement in these complex mathematical topics (Zengin & Tatar, 2017). It was found in other studies that students understood concepts better in the settings where GeoGebra was used (Thambi & Eu, 2013; Zengin & Tatar, 2017), and their interest and motivation in the course increased (Zengin & Tatar, 2017). Based on students' perceptions, it was found that the visualizations used in cooperative learning supported by GeoGebra made the concepts meaningful, and an enjoyable learning environment was created by integrating GeoGebra

(Zengin & Tatar, 2017). Similarly, Arbain and Shukor (2015) investigated the effectiveness of using GeoGebra on mathematics learning among 62 students. Arbain and Shukor (2015) concluded that students positively perceive learning and have better learning achievement when they use GeoGebra in learning mathematics. Although recent studies showed that students have positive perceptions of using GeoGebra and studies also explored that GeoGebra improves student achievement. The studies that examined the correlation between students` achievement and perception are limited. The results of my study contributed to the current literature and confirmed that a significant relationship exists between students' perceptions of using GeoGebra and their geometric transformations achievement test.

Students' Perceptions of Using GeoGebra in Learning Geometric Transformations

Research Question 3: What are student perceptions about using GeoGebra in learning geometric transformations?

Null Hypothesis (H_0) 3: Students generally provided negative feedback about using GeoGebra in learning geometric transformations.

Alternative Hypothesis (H_1) 3**:** Students generally provided positive feedback about using GeoGebra in learning geometric transformations.

The third research question explored students' perceptions of using GeoGebra in learning geometric transformations, calculated by descriptive statistics and frequencies and percentages. A summary of key findings followed by a discussion of the students' perceptions of using GeoGebra in learning geometric transformations and the connections with recent research.

Descriptive statistics and frequencies and percentages were used for student perceptions about using GeoGebra in learning geometric transformations. Ibibo and Tubona (2019) used a calculation to find the criterion means for students' perception of GeoGebra software (SPGS). The SPGS was a 13-item questionnaire structured in a four-point Likert scale of 4-Strongly Agree (SA), 3-Agree (A), 2-Disagree (D), and 1-Strongly Disagree (SD) with a criterion mean of 2.50. I used a calculation to find the criterion means for students' perception of using GeoGebra. It was a 15-item questionnaire structured on a five-point Likert scale of 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, and 5-Strongly Agree. The criterion mean in my study was calculated that the average of Strongly Disagree (1.00 points) and Strongly Agree (5.00 points) is 3.00 points. The result showed that all items 6 to item 20 have a mean of 3.00 points, which was greater than the criterion means of 3.00, except for item 20, which recorded a mean of 2.48. Item 20 is related to the curriculum-related item that GeoGebra should be used in other mathematics courses such as Algebra and Calculus. The participants do not recommend using GeoGebra in other mathematics courses.

This study showed that students positively perceived GeoGebra in learning geometric transformations. In other words, the result showed that the level of students' perceptions of using GeoGebra in learning geometric transformations was found to be positive. The result also indicated that the GeoGebra helps learn geometry concepts, visualize geometry content, and make students more creative, enjoyable, and confident. The findings of this study showed that GeoGebra is an excellent tool for learning geometric transformations.

The participants highly agreed that GeoGebra is a user-friendly and effective tool in learning geometry, and GeoGebra helped them to visualize and provide meaningful information. According to the questionnaire results, students perceived that GeoGebra allowed learning content to be playful and motivating and helped them understand the content better. Also, the participants highly agreed that the GeoGebra is an effective tool for understanding geometry concepts and increasing achievement. Students also found that using GeoGebra was more enjoyable in learning geometric transformations than in direct instruction.

Shadaan and Eu (2013) and Arbain and Shukor (2015) found similar results on students' perceptions. Shadaan and Eu (2013) and Arbain and Shukor (2015) conducted a study on students' perception of using GeoGebra and concluded that students had a positive perception of using GeoGebra. Similarly, Ocal (2017); Zulnaidi and Zamri (2017) indicated that the GeoGebra is a good tool for developing conceptual understanding. Lavicza and Prodromou (2017) and Wah (2015) found that GeoGebra is an excellent resource for student attitude, attention, relevance, and confidence.

The current study verified that GeoGebra is an effective tool for students learning geometric transformations and visualizing and manipulating geometry topics. GeoGebra significantly affects students' perceptions and their achievement in learning geometric transformations. GeoGebra instructed classroom students and agreed that GeoGebra is an effective tool in learning geometry, understanding geometry concepts, increasing achievement, and visualizing geometry concepts. Students stated that GeoGebra made them more creative and made learning more enjoyable.

Conclusion

Previous studies focused on the impacts of using GeoGebra on students' perceptions (Arbain & Shukor, 2015; Ganesan & Eu, 2020; Joshi & Singh, 2020; Lavicza & Prodromou, 2017; Masri et al., 2016; Shadaan & Leong, 2013; Wah, 2015) or impacts of using GeoGebra on students' achievement in learning geometry (Jelatu & Ardana, 2018; Khalil, 2017; Khalil et al., 2018; Masri et al., 2016; Seloraji & Eu, 2017; Shadaan & Eu, 2013; Singh, 2018). However, I focused on the correlation between students' achievement and perception. Therefore, my study extends and adds value to the current studies. The main goal of this study was to evaluate the impacts of using GeoGebra on students' perceptions and their achievement in learning geometric transformations. A statistically significant difference exists in the experimental and control groups' geometric transformations achievement test scores. I concluded that there are statistically significant differences in students' achievement test scores between the experimental group who received instruction with GeoGebra and the control group who received instruction without GeoGebra in geometric transformations. Therefore, GeoGebra affects students' achievements in geometric transformations. A statistically significant relationship exists between students' perceptions of using GeoGebra and their geometric transformations achievement test. I concluded that a significant positive correlation was observed between perceptions of using GeoGebra and the geometric transformations achievement test, with a correlation of 0.26, indicating a small effect size. This suggests that as perceptions of using GeoGebra increase, the geometric transformations achievement test tends to increase. Students generally provide positive feedback about using GeoGebra in learning geometric transformations. The results of the students' perception of using GeoGebra showed that the level of students' perceptions of using GeoGebra in learning geometric transformations was positive. GeoGebra helped learn geometry concepts, visualize geometry content, and make students more creative, enjoyable, and confident. The findings of this study showed that GeoGebra is an excellent tool for learning geometric transformations.

Future Research

The most important recommendation for further research relates to the length of the intervention to evaluate the impacts of using GeoGebra on students' perceptions and their achievement in learning geometric transformations. It would be noteworthy to assess the effects of using GeoGebra on students' perceptions and their achievement in learning geometric transformations on a long-term intervention. In addition, it might be interesting to investigate the impact of using GeoGebra on students' perceptions and their achievement when learning geometric transformations in a more heterogeneous population. Finally, it would be paramount to compare the effects of using GeoGebra on students' perceptions and their achievement in learning geometric transformations in low and high-achieving students.

Limitations

This dissertation had several limitations that require discretion in interpreting the results. The first limitation of this study was that the research was not entirely experimental design because I used existing classrooms of students to compare the experimental and control groups. The second limitation of this study was one place where the study was conducted in one school with specific grade levels; the study was conducted in one public charter school with six geometry classes, only 9th-grade and 10th-grade students (n = 131). Another limitation of this study was using convenience sampling rather than random sampling. The research was limited to a small group of students (n = 131) of 9^{th} and 10^{th}-grade students, so additional research is needed on different classes with similar content.

Implications

This study provided strong evidence that using GeoGebra affected students' perception and achievement when they learned geometric transformations. This study showed that students had the potential to explore GeoGebra on their own and get a feel for the concept with minimal teacher support. It was also concluded that it sparked students' interest in interacting with

GeoGebra. Although the reviewed studies showed that GeoGebra is more effective in teaching and learning geometry, one needs to know why most of the reviewed studies were conducted in geometry while few were conducted in other fields. As GeoGebra integration in science, technology, engineering, and mathematics continues to be adopted by many countries, further studies need to be conducted to investigate the extent to which GeoGebra integration adds value to mathematics learning. Because GeoGebra integration cannot replace a teacher in education, teachers need to be equipped with content knowledge, skills to use these technologies effectively, and pedagogy to facilitate teaching and learning processes about student achievement.

These research findings suggested to mathematics teachers that GeoGebra is a beneficial tool in learning mathematics and plays an essential role in improving students' achievement. Therefore, mathematics teachers could use GeoGebra while they teach mathematics. In addition, it is recommended that the curriculum developers and textbook writers incorporate GeoGebra activities into the curriculum and textbooks for geometric transformations and other content.

REFERENCES

Abramovich, S. (2013). Computers in mathematics education: An introduction. *Computers in the Schools, 30*(1-2), 4-11.

Adelabu, F. M., Makgato, M., & Ramaligela, M. S. (2019). The importance of dynamic geometry computer software on learners' performance in geometry. *Electronic Journal of E-Learning, 17*(1), 52-63.

Arbain, N., & Shukor, N. A. (2015). The effects of GeoGebra on student achievement. *Procedia-Social and Behavioral Sciences, 172*, 208-214.

Bayaga, A., Mthethwa, M. M., Bossa, M. J., & Williams, D. (2019). Impacts of implementing GeoGebra on eleventh-grade students learning of Euclidean Geometry. *South African Journal of Higher Education, 33*(6), 32-54.

Bishnoi, N. (2017). Collaborative learning: A learning tool advantages and disadvantages. *Indian Journal of Health & Wellbeing, 8*(8), 789-791.

Bonwell, C. C., & Eison, J. A. (1991). *Active learning: Creating excitement in the classroom.* The George Washington University.

Bulut, M., Akcakın, H. U., Kaya, G., & Akcakin, V. (2016). The effects of GeoGebra on third grade primary students' academic achievement in fractions. *International Society of Educational Research (ISER), Mathematics Education, 11*(2), 347-355.

Bwalya, D. (2019). Influence of GeoGebra on students' achievement in geometric transformations and attitude towards learning mathematics with technology. *Journal of Education and Practice, 10*(13), 25-36.

Chalaune, B. B., & Subedi, A. (2020). Effectiveness of GeoGebra in teaching school mathematics. *Contemporary Research: An Interdisciplinary Academic Journal, 4*(1), 46-58.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). West Publishing Company.

Common Core State Standards Initiative (CCSSI) (2010). Common core state standards for mathematics. National Governors Association Center for Best Practices and the Council of Chief State School Officers.

Conover, W. J., & Iman, R. L. (1981). Rank transformations as a bridge between parametric and nonparametric statistics. *The American Statistician, 35*(3), 124-129.

Creswell, J. W. (2015). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (5th ed.). Pearson.

Darling-Hammond, L., Zielezinski, M. B., & Goldman, S. (2014). *Using technology to support at-risk students' learning.* Alliance for Excellent Education.

Emaikwu, S. O., Iji, C. O., & Abari, M. T. (2015). Effect of GeoGebra on senior secondary school students' interest and achievement in statistics in Makurdi local government area of Benue State, Nigeria. *Journal of Mathematics (IOSRJM), 2*(3), 14-21.

Ernest, P. (1998). *Social constructivism as a philosophy of mathematics*. SUNY Press.

Ezeanyanike, P. A. (2013). Assessing benefits of collaborative learning environment for quality higher education in Nigeria. *Journal of Educational and Social Research, 3*(6), 85-94.

Firdaus, F., Kailani, I., Bakar, M. N. B., & Bakry, B. (2015). Developing critical thinking skills of students in mathematics learning. *Journal of Education and Learning, 9*(3), 226-236.

Ganesan, N., & Eu, L. K. (2020). The effect of dynamic geometry software Geometer's sketchpad on students' achievement in topic circle among form two students. *Malaysian Online Journal of Educational Technology,* 8(2), 58-68.

Garba, A. (2019). Issues and challenges in the use of GeoGebra in teaching and learning of mathematics in secondary schools in Makurdi Metropolis. *EPH-International Journal of Business & Management Science, 5*(12), 1-19.

George, D., & Mallery, P. (2020). *IBM SPSS statistics 26 step by step* (16th ed.). Routledge.

Gravetter, F. J., & Forzano, L. B. (2019). *Research methods for the behavioral sciences* (6th ed.). Cengage.

Haciomeroglu, E. S., & Andreasen, J. B. (2013). Exploring calculus with dynamic mathematics software. *Mathematics and Computer Education, 47*(1), 6-18.

Herbst, P., Fujita, T., Halverscheid, S., & Weiss, M. (2017). *The learning and teaching of geometry in secondary schools: A modeling perspective*. Routledge.

Hurst, B., Wallace, R., & Nixon, S. B. (2013). The impact of social interaction on student learning. *Reading Horizons: A Journal of Literacy and Language Arts, 52*(4), 375-398.

Ibibo, C.G., & Tubona, G. (2019). Students' perception and performance across ability levels on GeoGebra software usage in learning of circle geometry. *International Journal of Statistics and Applied Mathematics; 4*(4), 7-11.

Ibrahim, K., & Ilyas, Y. (2016). Teaching a concept with GeoGebra: Periodicity of trigonometric functions. *Educational Research and Reviews, 11*(8), 573–581.

Jelatu, S., & Ardana, I. (2018). Effect of GeoGebra-aided react strategy on understanding of geometry concepts. *International journal of instruction, 11*(4), 325-336.

Joshi, D. R., & Singh, K. B. (2020). Effect of using GeoGebra on eighth-grade students' understanding in learning linear equations. *Editorial from Bronisław Czarnocha, 12*(3), 76-83.

Khalil, M. (2017). Exploration of mathematical thinking and its development through GeoGebra. *Journal of Educational Research, 20*(1), 83-99.

Khalil, M., Farooq, R. A., Cakiroglu, E., Khalil, U., & Khan, D. M. (2018). The development of mathematical achievement in the analytic geometry of grade-12 students through GeoGebra activities. *Eurasia Journal of Mathematics, Science, and Technology Education, 14*(4), 1453-1463.

Kirby, J. R., & Boulter, D. R. (1999). Spatial ability and transformation geometry. *European Journal of Psychology of Education, 14*(2), 283-294.

Kushwaha, R. C., Chaurasia, P. K., & Singhal, A. (2014). Impact on students' achievement in teaching mathematics using GeoGebra. *Proceedings - IEEE 6th International Conference on Technology for Education, T4E 2014*, 134-137.

Kutluca, T. (2013). The effect of geometry instruction with dynamic geometry software; GeoGebra on Van Hiele geometry understanding levels of students. *Educational Research and Reviews, 8*(17), 1509-1518.

Laal, M., & Ghodsi, S. M. (2012). Benefits of collaborative learning. *Procedia - Social and Behavioral Sciences, 31,* 486-490.

Lahann, P., & Lambdin, D. V. (2020). Collaborative Learning in Mathematics Education. In: Lerman S. (eds). *Encyclopedia of Mathematics Education*. Springer.

Lavicza, Z., & Prodromou, T. (2017). Integrating technology into mathematics education in an entire educational system - Reaching a critical mass of teachers and schools. *International Journal for Technology in Mathematics Education, 24*(3), 1-6.

Lee, E., & Hannafin, M. J. (2016). A design framework for enhancing student-centered learning engagement: Own it, learn it, and share it. *Educational Technology Research and Development, 64*(4), 707-734.

Lopes, R. P., Mesquita, C., Rio-Rama, M. D. L. C. D., & Alvarez-Garcia, J. (2018). Collaborative learning experiences for the development of higher-order thinking. *Espacios, 39*(17), 1-16.

Majerek, D. (2014). Application of GeoGebra for teaching mathematics. *Advances in science and technology research journal, 8*(24), 51-54.

Masri, R., Hiong, T. S., Tajudin, M., & Zamzamin, Z. Z. (2016). The effects of using GeoGebra teaching strategy in Malaysian secondary schools: A case study from Sibu, Sarawak. *Geografia - Malaysian Journal of Society and Space, 12*(7), 13-25.

Mills, G. E., & Gay, L. R. (2019). *Educational research: Competencies for analysis and applications* (12th ed.). Pearson.

National Council of Teachers of Mathematics. (2000). *Standards for school mathematics.* The National Council of Teachers of Mathematics.

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematical success for all*. The National Council of Teachers of Mathematics.

National Council of Teachers of Mathematics. (2015). *Strategic use of technology in teaching and learning mathematics*. The National Council of Teachers of Mathematics.

National Governors Association Center for Best Practices & Council of Chief State School Officers (2010). *Common Core State Standards Mathematics*. National Governors Association Center for Best Practices, Council of Chief State School Officers.

Ocal, M. F. (2017). The effect of GeoGebra on students' conceptual and procedural knowledge: The case of applications of derivative. *Higher Education Studies, 7*(2), 67-78.

Ozcakir, B., Aytekin, C., Altunkaya, B., & Doruk, B. K. (2015). Effects of using dynamic geometry activities on eighth grade students' achievement levels and estimation performances in triangles. *Participatory Educational Research, 2*(3), 43-54.

Ozdamli, F., Karabey, D., & Nizamoglu, B. (2013). The effect of technology-supported collaborative learning settings on the behavior of students towards Mathematics learning. *Procedia-Social and Behavioral Sciences, 83*, 1063-1067.

Polman, J., Hornstra, L., & Volman, M. (2020). The meaning of meaningful learning in mathematics in upper-primary education. *Learning Environments Research*, 1-18.

Rahman, T., Bandeira de Mello, V., Fox, M. A., & Ji, C. S. (2019). Mapping state proficiency standards onto the NAEP scales: Results from the 2017 NAEP reading and mathematics assessments. *NCES, 2019-040. National Center for Education Statistics.*

Reis, Z. A., & Ozdemir, S. (2010). Using GeoGebra as an information technology tool: Parabola teaching. *Procedia-Social and Behavioral Sciences, 9*, 565-572.

Saha, R. A., Ayub, A. F. M., & Tarmizi, R. A. (2010). The effects of GeoGebra on mathematics achievement: Enlightening coordinate geometry learning. *Procedia - Social and Behavioral Sciences, 8,* 686-693.

Schunk, D. (2019). *Learning theories: An educational perspective* (8th ed). Pearson.

Seloraji, P., & Eu, L. K. (2017). Students' performance in geometrical reflection using GeoGebra. *Malaysia Online Journal of Educational Technology, 5*(1), 65-77.

Serin, H. (2018). Perspectives on the teaching of geometry: Teaching and learning methods. *Journal of Education and Training, 5*(1), 131-137.

Shadaan, P., & Eu, L. K. (2013). Effectiveness of using GeoGebra on students' understanding in learning circles. *Malaysia Online Journal of Educational Technology, 1*(4), 1-11.

Shadaan, P., & Leong, K. E. (2013). Effectiveness of using GeoGebra on students' understanding of learning circles. *Malaysian Online Journal of Educational Technology, 1*(4), 1-11.

Singh, L. K. (2018). Impact of using GeoGebra software on students' achievement in geometry: A study at secondary level. *Asian Resonance, 7*(5), 133–137.

Stockemer, D. (2018). *Quantitative methods for the social sciences: A practical introduction with examples in SPSS and Stata*. Springer International Publishing.

Tamam, B., & Dasari, D. (2021). The use of GeoGebra software in teaching mathematics. *Journal of Physics: Conference Series, 1882*(1), 1-6.

Tatar, E., & Zengin, Y. (2016). Conceptual understanding of definite integral with GeoGebra. *Computers in the Schools, 33*(2), 120-132.

Tay, M. K. (2018). Effect of using GeoGebra on senior high school students' performance in circle theorems. *African Journal of Educational Studies in Mathematics and Sciences, 14*(0), 1–18.

Thambi, N., & Eu, L. K. (2013). Effect of students' achievement in fractions using GeoGebra. *Sainsab, 16*, 97-106.

Thorndike, E., & Barnhart, C. (1993). *Advanced dictionary*. Scott Foresman and Company.

Uygun, T., & Akyuz, D. (2019). Developing subject matter knowledge through argumentation. *International Journal of Research in Education and Science, 5*(2), 532-547.

Uygun, T. (2020). An inquiry-based design research for teaching geometric transformations by developing mathematical practices in a dynamic geometry environment. *Mathematics Education Research Journal, 32(*3), 523-549.

Wah, L. K. (2015). The effects of instruction using the arcs model and GeoGebra on Upper secondary students' motivation and achievement in learning combined transformation. *Asia Pacific Journal of Educators and Education, 30*(5), 141-158.

Wassie, Y. A., & Zergaw, G. A. (2019). Some of the potential affordances, challenges, and limitations of using GeoGebra in mathematics education. *Eurasia Journal of Mathematics, Science and Technology Education, 15*(8), 1-11.

Westfall, P. H., & Henning, K. S. S. (2013). *Texts in statistical science: Understanding advanced statistical methods.* Taylor & Francis.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Harvard University Press.

Zengin, Y., Furkan, H., & Kutluca, T. (2012). The effect of dynamic mathematics software GeoGebra on student achievement in teaching trigonometry. *Procedia-Social and Behavioral Sciences*, *31*, 183–187.

Zengin, Y., & Tatar, E. (2017). Integrating dynamic mathematics software into cooperative learning environments in mathematics. *Educational Technology & Society, 20*(2), 74-88.

Zulnaidi, H., & Zakaria, E. (2012). The effect of using GeoGebra on conceptual and procedural knowledge of high school mathematics students. *Asian Social Science, 8*(11), 102-106.

Zulnaidi, H., & Zamri, S. N. A. S. (2017). The effectiveness of the GeoGebra software: The intermediary role of procedural knowledge on students' conceptual knowledge and their achievement in mathematics. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(6), 2155-2180.

APPENDIX A

APPENDIX A

GEOMETRIC TRANSFORMATIONS ACHIEVEMENT TEST (PRETEST AND POSTTEST)

Geometric Transformations Achievement Test

Name: Section:

Directions:

This test contains 20 multiple-choice questions.

1. Please read each question carefully.

2. There is only one correct answer for each question.

3. Use the space provided in this test booklet for figuring or drawing.

4. If you want to change an answer, please erase the first answer.

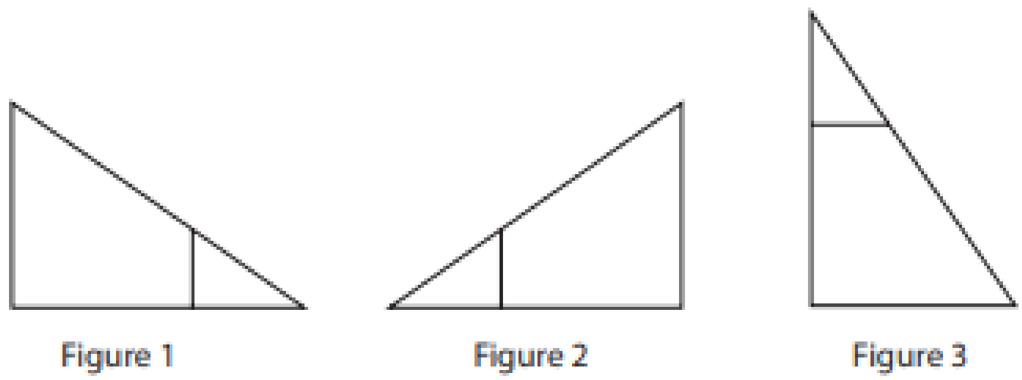
5. If you need a pencil and an eraser, please raise your hand.

6. You have 45 minutes for this test.

Wait until the instructor says that you may begin.

Geometric Transformations Achievement Test

1. Which of these transformations, taken in order, can be used so that Figure 1 above becomes Figure 2 and then Figure 3?



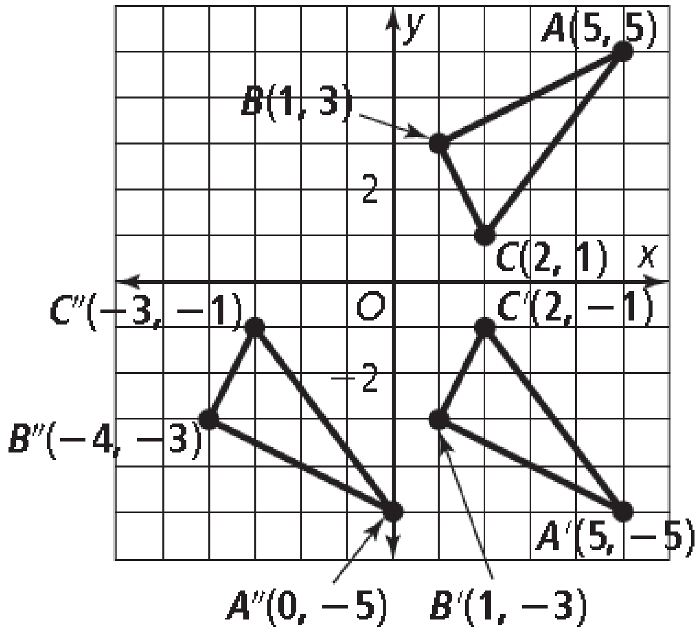
A. Reflection and then translation

B. Reflection and then $\frac{1}{4}$ turn rotation clockwise

C. $\frac{1}{2}$ turn rotation and then translation

D. $\frac{1}{4}$ $t$urn rotation counterclockwise and then reflection

2. Which of the descriptions is true for the graph?



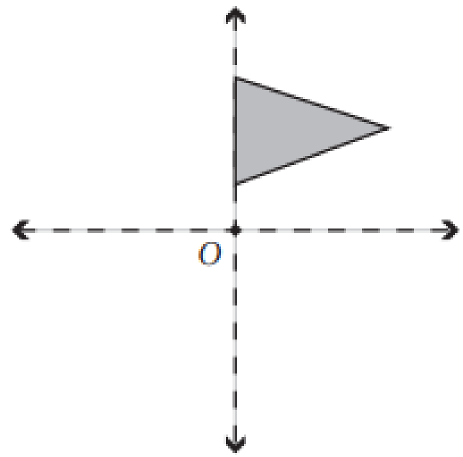
A. △A′B′C′ is $T_{\langle 0, -2\rangle}$ (△ABC)

B. △A′B′C′ is ($T_{\langle 0, -2\rangle} \circ R_{x\text{-axis}}$) (△ABC)

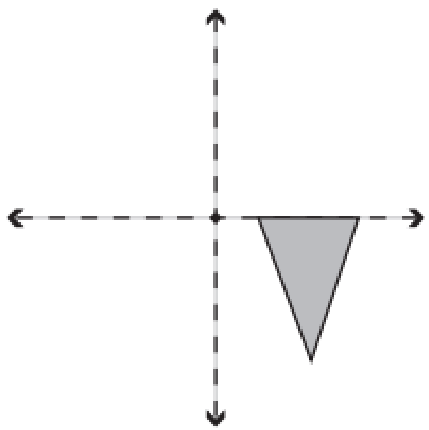
C. △A′B′C′ is $R_{x\text{-axis}}$(△ABC)

D. △A′B′C′ is $r_{90°}$(△ABC)

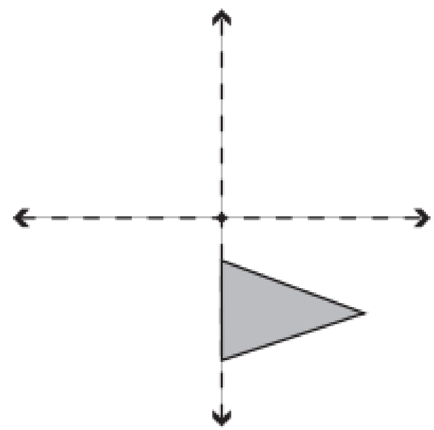
3. Which of these shows the result of a half-turn clockwise around point O?



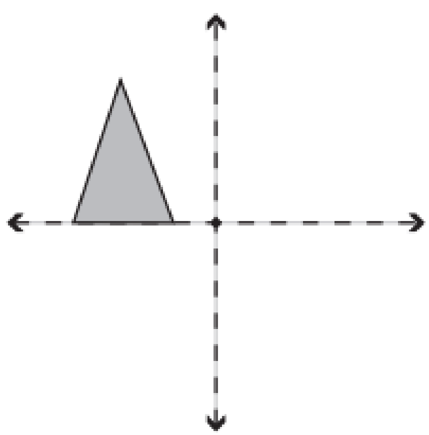
A.



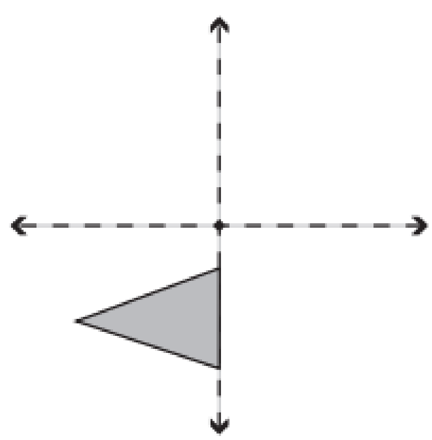
B.



C.



D.



4. How many lines of symmetry do an equilateral triangle have?

A. 4

B. 3

C. 2

D. 1

5. Point T is at (–2, 5). What are the coordinates of point T′ after being translated 6 units down and reflected across the y-axis?

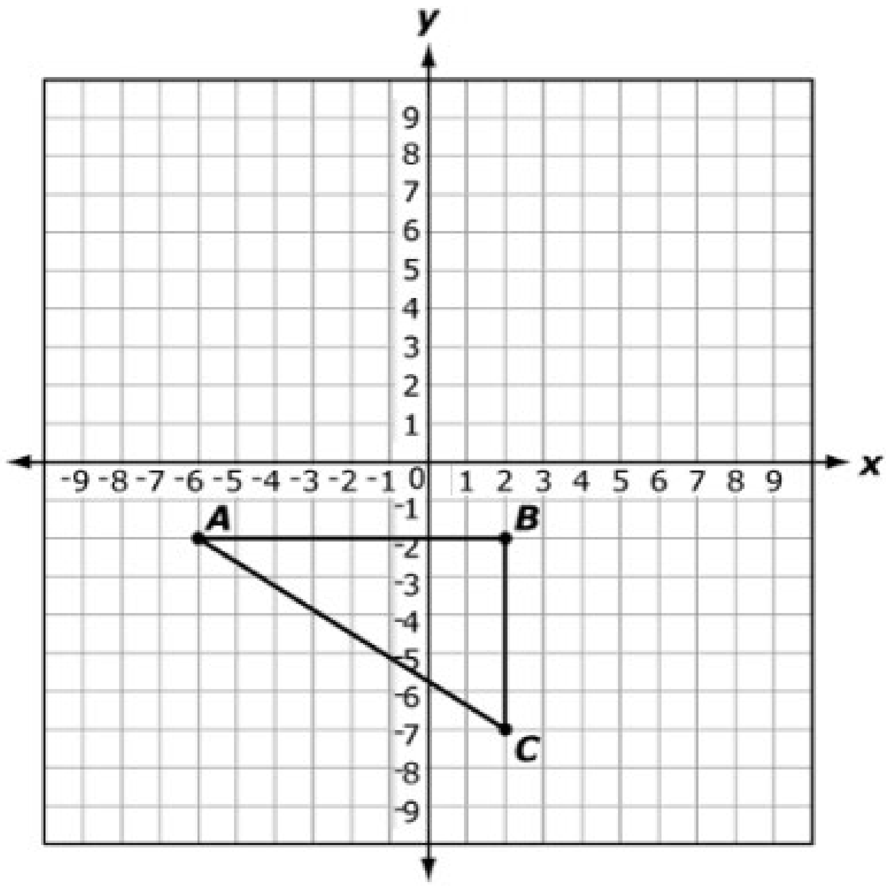
A. (2, -1)

B. (-2, -5)

C. (2, 1)

D. (-2, 5)

6. Triangle ABC translated 8 units up and 3 units left to create a new triangle A′B′C′.



Which order pairs show the coordinate of the vertices of triangle A′B′C′?

A. A′ (-6, 6), B′ (2, 6), and C′ (2, 1)

B. A′ (-6, 6), B′ (2, 6), and C′ (2, -1)

C. A′ (-9, 6), B′ (1, 6), and C′ (-1, 1)

D. A′ (-9, 6), B′ (-1, 6), and C′ (-1, 1)

7. How many lines of symmetry do the pentagon have?

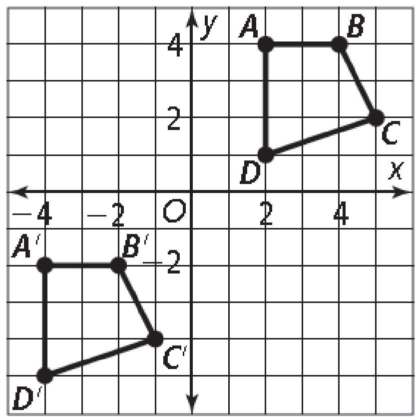
A. 2

B. 3

C. 4

D. 5

8. Which of the following descriptions apply to the transformation?



A. $T_{\langle 6, -6 \rangle}$

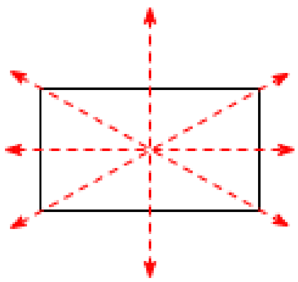
B. 6 units down; 6 units left

C. 6 units up; 6 units right

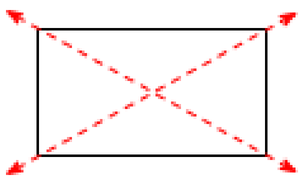
D. $T_{\langle 6, 6 \rangle}$

9. The following rectangle has rotational symmetry.

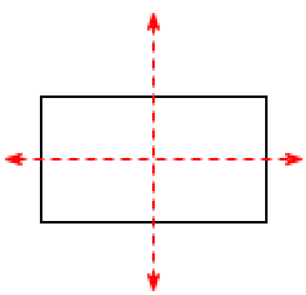
Which choice below shows all the lines of symmetry for the figure?



A.



B.



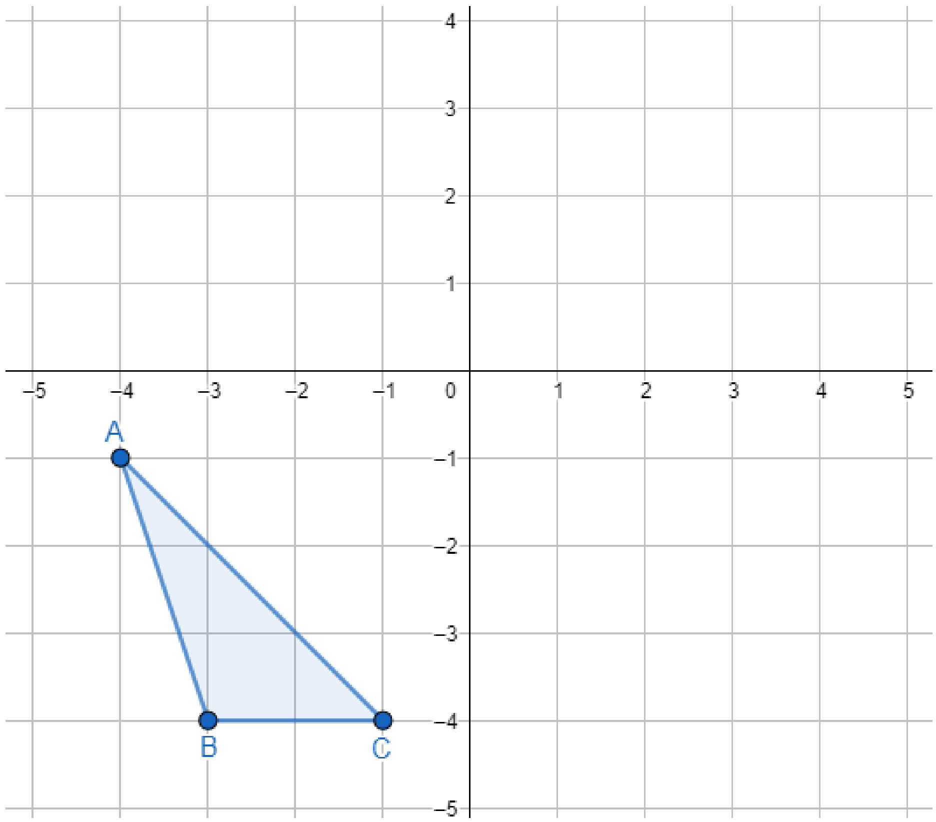
C.

D. The figure has no lines of symmetry.

10. Perform the following two transformations on the graph below.

(1) Triangle ABC reflected across the y-axis

(2) Rotate triangle ABC 90° counterclockwise (↺) about center O (0, 0).



Which order pairs show the coordinate of the vertices of triangle A′B′C′?

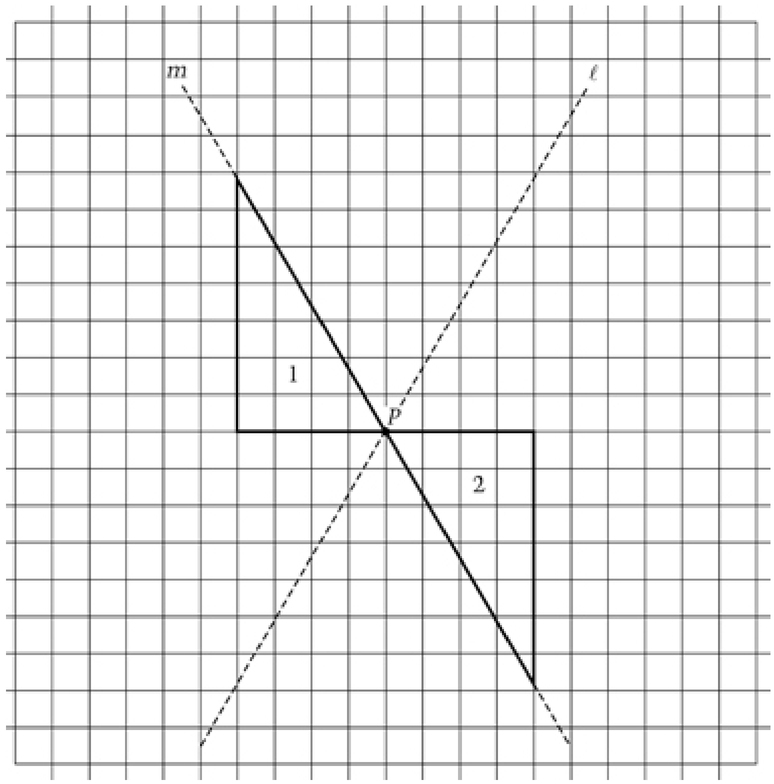
A. A′ (1, 4), B′ (4, 3), and C′ (4, 1)

B. A′ (-1, 4), B′ (4, 3), and C′ (4, 1)

C. A′ (1, 4), B′ (4, -3), and C′ (4, -1)

D. A′ (1, 4), B′ (-4, 3), and C′ (4, -1)

11. For this question, you may want to use your pieces labeled X. The figure below shows two triangles, labeled 1 and 2.



Which one of the following describes a way to move triangle 1 so that it completely covers triangle 2?

A. Turn (rotate) 180 degrees about point P.

B. Flip (reflect) over line ℓ.

C. Slide (translate) 5 units to the right, followed by 8 units down.

D. Slide (translate) 10 units to the right, followed by 16 units down.

12. Quadrilateral ABCD has coordinates A (−2, 0), B (0, 4), C (4, 6), and D (2, 2). What are the coordinates of the Quadrilateral ABCD after Quadrilateral ABCD is reflected on the x-axis?

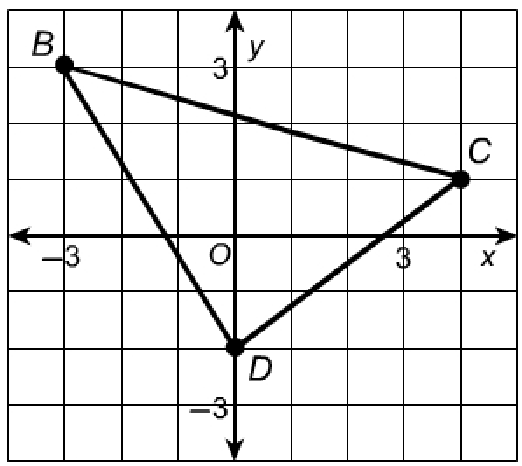
A. A′ (2, 0), B′ (0, 4), C′ (4, 6), and D′ (2, 2)

B. A′ (2, 0), B′ (0, -4), C′ (4, 6), and D′ (2, 2)

C. A′ (−2, 0), B′ (0, -4), C′ (4, -6), and D′ (2, -2)

D. A′ (−2, 0), B′ (0, 4), C′ (4, -6), and D′ (2, -2)

13. Use △BCD in the figure shown. What are the vertices of the image after the triangle is rotated 90° clockwise about the origin?



A. B' (−3, −3), C' (−1, 4), D' (2, 0)

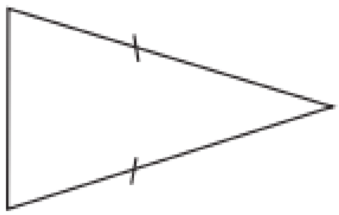
B. B' (3, −3), C' (1, 4), D' (0, 2)

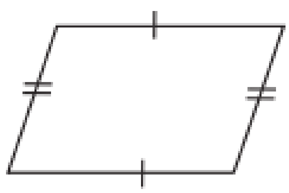
C. B' (3, 3), C' (1, −4), D' (−2, 0)

D. B' (−3, −3), C' (−1, −4), D' (0, −2)

14. Which shape has a line of symmetry?

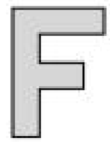
A. 

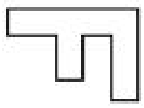
B. 

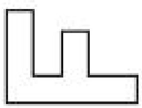
C. 

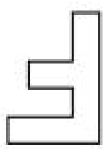
D. 

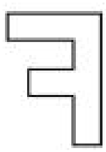
15. The figure below is shaded on the top side and white on the underside. If the figure were flipped over across the y-axis, its white side could look like which of the following figures?



A. 

B. 

C. 

D. 

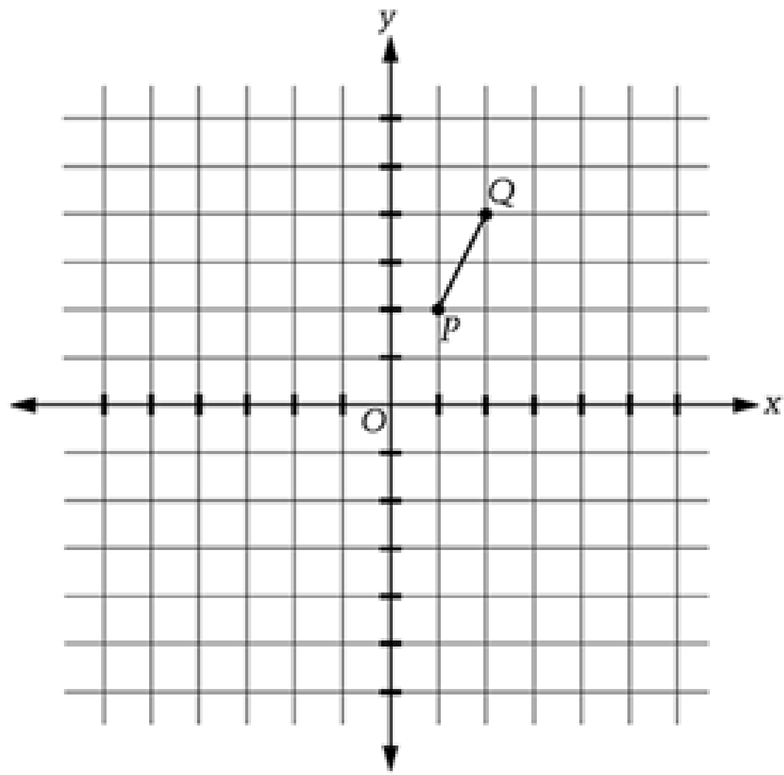
16. The rule $T_{\langle 4, -1\rangle}$ is used for point (2, –7). Where is the translated point in the coordinate system?

- A. Quadrant I
- B. Quadrant II
- C. Quadrant III
- D. Quadrant IV

17. Perform the following two transformations on the graph below.

(1) Rotate the segment 90° counterclockwise (↺) about point P.

(2) Reflect on the segment you drew in part (1) across the x-axis.



After each transformation, what could be the new coordinate of the points?

A. P' (1, 2) and Q' (-1, -3)

B. P' (1, -2) and Q' (-1, 3)

C. P' (1, -2) and Q' (-1, -3)

D. P' (1, 2) and Q' (1, -3)

18. If a figure is translated with the rule $T_{\langle -5, 3\rangle}$, which translation moves the image back to the original position?

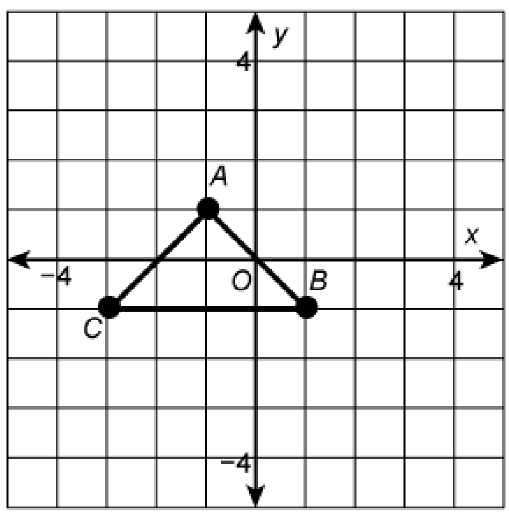
A. $T_{\langle 5, -3\rangle}$

B. $T_{\langle -5, 3\rangle}$

C. $T_{\langle 0, 5\rangle}$

D. $T_{\langle -5, 0\rangle}$

19. After a reflection of the figure, the image vertices are $A'(5, 1)$, $B'(3, -1)$, and $C'(7, -1)$. What is the line of reflection?



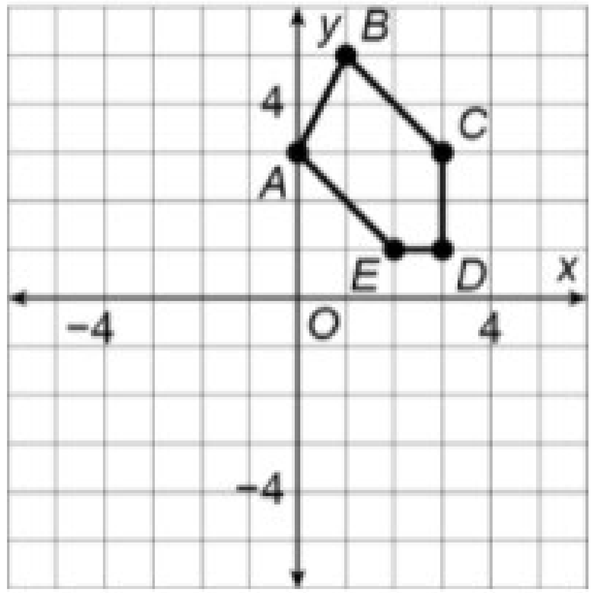
A. x = 2

B. x = -2

C. y = 2x

D. y = -2x

20. Use pentagon ABCDE.



What are the coordinates of E′ after the pentagon is rotated 270° about the origin?

A. (-1, 2)

B. (1, -2)

C. (-1, -2)

D. (1, 2)

Geometric Transformations Achievement Test Answer Keys, Categories, & Difficult Levels

Item Number	Correct Answer	Category	Difficult Level / Depth of Knowledge (DOK) Level	Reason
1	B	Rigid - Motion Transformations	Hard / Level 3 (Strategic Thinking)	This item is a DOK 3 because it requires the student to perform a compound transformation of a geometric figure within a coordinate plane.
2	C	Reflection	Hard / Level 3 (Strategic Thinking)	This item is a DOK 3 because it requires the student to perform a geometric transformation to meet specified criteria.
3	D	Rotation	Medium / Level 2 (Skills / Concept)	This item is a DOK 2 because it requires the student to visualize and then identify the rule of transformation of a two-dimensional figure.
4	B	Symmetry	Medium / Level 2 (Skills / Concept)	This item is a DOK 2 because it requires the student to identify the equilateral triangle and apply geometric transformation within a coordinate plane.
5	A	Rigid - Motion Transformations	Hard / Level 3 (Strategic Thinking)	This item is a DOK 3 because it requires the student to perform a compound transformation of a point within a coordinate plane.

6	D	Translation	Medium / Level 2 (Skills / Concept)	This item is a DOK 2 because it requires the student to perform translations and then identify the vertices of the translated figure.
7	D	Symmetry	Medium / Level 2 (Skills / Concept)	This item is a DOK 2 because it requires the student to identify the pentagon and apply geometric transformation within a coordinate plane.
8	B	Translation	Medium / Level 2 (Skills / Concept)	This item is a DOK 2 because it requires the student to visualize and then identify the rule of transformation of a two-dimensional figure.
9	C	Symmetry	Medium / Level 2 (Skills / Concept)	This item is a DOK 2 because it requires the student to identify and apply geometric transformation within a coordinate plane.
10	A	Rigid - Motion Transformations	Hard / Level 3 (Strategic Thinking)	This item is a DOK 3 because it requires the student to perform a compound transformation of a geometric figure within a coordinate plane.
11	A	Rotation	Medium / Level 2 (Skills / Concept)	This item is a DOK 2 because it requires the student to visualize and then identify steps in a transformation of a two-dimensional figure.

12	C	Reflection	Medium / Level 2 (Skills / Concept)	This item is a DOK 2 because it requires the student to visualize and then identify the rule of transformations of a two-dimensional figure.
13	C	Rotation	Hard / Level 3 (Strategic Thinking)	This item is a DOK 3 because it requires the student to visualize and then identify steps in a transformation of a two-dimensional figure.
14	B	Symmetry	Medium / Level 2 (Skills / Concept)	This item is a DOK 2 because it requires the student to visualize and find the one with lines of symmetry.
15	D	Reflection	Easy / Level 1 (Recall and Reproduction)	This item is a DOK 1 because it requires the student to identify the result of transformation.
16	D	Translation	Medium / Level 2 (Skills / Concept)	This item is a DOK 2 because it requires the student to identify where the translated point is in a coordinate plane.
17	C	Rigid - Motion Transformations	Hard / Level 3 (Strategic Thinking)	This item is a DOK 3 because it requires the student to perform a compound transformation of a geometric figure within a coordinate plane.
18	A	Translation	Easy / Level 1 (Recall and Reproduction)	This item is a DOK 1 because it requires the student to identify translation and moves the image back to the original position.

19	A	Reflection	Hard / Level 3 (Strategic Thinking)	This item is a DOK 3 because it requires the student to perform a line of reflection within a coordinate plane.
20	B	Rotation	Hard / Level 3 (Strategic Thinking)	This item is a DOK 3 because it requires the student to visualize and then identify steps in a transformation of a two-dimensional figure.

Categories of Questions

Category	Questions
Rigid - Motion Transformations	1, 5, 10, 17
Rotation	3, 11, 13, 20
Reflection	2, 12, 15, 19
Translation	6, 8, 16, 18
Symmetry	4, 7, 9, 14

Difficult Level / Depth of Knowledge (DOK) Level and Scoring Points

Difficult Level / Depth of Knowledge (DOK) Level	Point for Each Correct Answer	Questions
Easy / Level 1 (Recall and Reproduction)	1 point	15, 18
Medium / Level 2 (Skills / Concept)	2 points	3, 4, 6, 7, 8, 9, 11, 12, 14, 16
Hard / Level 3 (Strategic Thinking)	3 points	1, 2, 5, 10, 13, 17, 19, 20

APPENDIX B

APPENDIX B

STUDENTS' PERCEPTIONS OF USING GEOGEBRA QUESTIONNAIRE

Students' Perceptions of Using GeoGebra Questionnaire

Instructions:

This questionnaire is designed to measure your perceptions on the level of using GeoGebra. There is no right or wrong answer for each question. However, you should respond as accurately as possible by checking the most appropriate response. Thank you for participating.

Section 1. General Information

1.Your Name:

2.Your Section:

3.What is your gender?

__Female __Male

4.How old are you?

__Under 15 years old

__15 years old

__16 years old

__Above 16 years old

5.What is your ethnic background?

__Hispanic

__American Indian or Alaska Native

__Asian

__Black or African American

__White

Section 2. Students' Perceptions of Using GeoGebra

6. GeoGebra helped to increase my achievement in geometry.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

7. I have difficulty learning geometric transformations using GeoGebra.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

8. GeoGebra helped me think critically when learning geometry.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

9. Using GeoGebra distracted me when I was learning geometric transformations.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

10. GeoGebra is an essential software in learning geometry.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

11. I learned geometry better when the teacher taught without GeoGebra rather than when the teacher taught with GeoGebra.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

12. GeoGebra helped me visualize geometric transformations.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

13. GeoGebra helped me learn geometry more effectively when I learned geometry with GeoGebra than when I learned geometry without GeoGebra.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

14. GeoGebra is not friendly to use in learning geometric transformations.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

15. GeoGebra provided meaningful instruction on the topic of geometric transformations.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

16. GeoGebra made me lazy in learning geometric transformations.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

17. GeoGebra allowed me to learn geometric transformations in a playful and motivating way.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

18. Every school should use GeoGebra to teach geometry concepts.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

19. GeoGebra did not help me learn geometric transformations because the class environment became noisy while we used GeoGebra.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

20. GeoGebra should be used in other mathematics courses such as Algebra and Calculus.

☐Strongly Disagree

☐Disagree

☐Neutral

☐Agree

☐Strongly Agree

Students' Perceptions of Using GeoGebra Questionnaire Coding

Group	Control (1)	Experimental (2)			
Gender	Female (1)	Male (2)			
Age	Under 15 years old (1)	15 years old (2)	16 years old (3)	Above 16 years old (4)	
Ethnic Background	Hispanic (1)	American Indian or Alaska Native (2)	Asian (3)	Black or African American (4)	White (5)
Questionnaire Likert-Scale	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)

Students' Perceptions of Using GeoGebra Questionnaire Category

Item Number	Category	Item Number	Category
6	Geometry	14	Geometric Transformations
7	Geometric Transformations	15	Geometric Transformations
8	Geometry	16	Geometric Transformations
9	Geometric Transformations	17	Geometric Transformations
10	Geometry	18	Curriculum
11	Geometry	19	Geometric Transformations
12	Geometric Transformations	20	Curriculum
13	Geometry		

BIOGRAPHICAL SKETCH

Veysel Karatas was born in Turkey and completed his entire education, including elementary education, secondary education, and bachelor's degree in Turkey. He received his master's degree in master of education in curriculum and instruction in mathematics education from North American University in 2017. He is a certified mathematics teacher for grades 4 through 12. He has worked as a mathematics teacher in public schools for seven years and as the district mathematics department head for the last four years. He received his doctoral degree in curriculum and instruction in mathematics education from the University of Texas Rio Grande Valley in December 2022. Email: veysel.karatas01@utrgv.edu