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DECODING THE GEOMETRIC PROOF: A RUBRIC-BASED ANALYSIS OF CONGRUENT TRIANGLE REASONING ERRORS AMONG ASIAN STUDENTS

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Abstract

This research delves into an examination of the errors prevalent in the reasoning and proof skills of Asian students when working with congruent triangles. The study involved 100 participants across Asia, aiming to identify and analyze specific challenges faced by students in comprehending and applying the five key congruent triangle theorems. Employing a standard graph set, the research revealed significant difficulties in multiple facets of students' engagement with congruent triangles. The findings illuminated a pronounced confusion among students concerning both the connotation and formal structure of the congruent triangle theorems. Notably, participants exhibited challenges in graphic analysis, struggling with the transformation between various representations, mathematical language, natural language, and graphical depictions. The study further identified a substantial obstacle in students' ability to articulate a coherent proof process, showcasing a deficiency in their grasp of logical reasoning. In response to these identified challenges, the article introduces a comprehensive rubric designed for the evaluation of students' congruent reasoning and proof. The rubric aims to provide educators and researchers with a systematic tool to assess and address the specific areas of difficulty highlighted in the study. By delineating clear criteria for evaluating students' understanding and application of congruent triangle theorems, the rubric seeks to contribute to the enhancement of instructional strategies and curriculum development in the realm of geometric reasoning.

Keywords: Congruent Triangles, Geometric Reasoning, Proof Process, Mathematical Language, Rubric Development.

1. Introduction

In the field of geometric reasoning, the analysis of students' misconceptions pertaining to the comprehension and application of congruent triangle theorems emerges as a pivotal undertaking aimed at improving educational methodologies on a global scale (Clements & Battista, 2022). This research examines the cognitive abilities of Asian students in the domain of congruent triangles, focusing specifically on their reasoning and proving skills. The study provides a thorough analysis of the difficulties encountered by these students when it comes to comprehending and effectively applying fundamental theorems related to congruent triangles. The study, which involved a sample of 100 participants from various regions in Asia, provides insights into the complex nature of errors observed in students' interactions with congruent triangles. The objective of this research is to contribute to the enhancement of instructional strategies and the development of curriculum.

The research paper examines a pervasive issue within the field of mathematics education, namely the difficulties encountered by pupils in comprehending geometric principles (National Council of Teachers of Mathematics, 2021). The comprehension of geometric reasoning plays a fundamental role in mathematical literacy on a global scale. It is of great importance to recognize the challenges that students encounter when dealing with congruent triangles, as this issue extends beyond local contexts. The findings derived from this study have the potential to enhance international dialogue regarding pedagogical methodologies and provide a valuable contribution to the worldwide endeavor of enhancing mathematics education. (Wu, H., & Li, Y. 2020).

The study examines the many educational environments and cultural factors that influence students' mathematics learning experiences in Asia, specifically within the continental setting (Shah & Nirmala, 2023). Asia is widely recognized for its exceptional performance in mathematics. However, this research aims to acknowledge and tackle the special difficulties that students have when working with congruent triangles. Koichu, B., &Levenson, E. (2023)

The study presented in this paper makes a valuable contribution to the ongoing academic discussion around mathematics education policies and practices in Asian countries, as highlighted by Mullis et al. (2020). The statement recognizes the existence of diverse educational systems and techniques that are commonly observed in various countries around the continent. Gaining insight into the distinct obstacles encountered by students in different countries can assist educators and policymakers in developing targeted interventions that are in accordance with the specific requirements of their respective national educational environments. Panaoura, A., &Panaoura, G. (2021)

The present study aims to fill a significant void in the existing body of knowledge regarding students' deficiencies in their ability to reason and demonstrate proficiency in dealing with congruent triangles, as identified by Hiebert and Grouws (2021). The comprehension and application of essential theorems related to congruent triangles pose significant challenges for students, as identified by research in the field of geometry. The problem statement highlights the necessity of implementing focused interventions aimed at improving students' geometric reasoning skills, addressing a significant gap in the existing educational context.

The investigation conducted by Wang and Leung (2022) holds a broader relevance that surpasses the mere discovery of faults. This paper presents a thorough rubric that has been developed for the purpose of assessing students' congruent reasoning and proof. The rubric serves as a systematic tool for educators and researchers to effectively address the specific issues that have been identified in this area. The primary objective of the rubric is to enhance instructional methodologies and curriculum development, with the ultimate goal of promoting a more profound comprehension of congruent triangles among students on a worldwide scale.

Theoretical Framework

The present study is grounded in a comprehensive theoretical framework that encompasses three fundamental domains: Mathematical Reasoning and Proof, Congruent Triangles Reasoning and Proof, and Errors in Geometry Reasoning and Proof. The study's theoretical framework is based on the broader domain of mathematical reasoning and proof. The approach integrates the ideas delineated by Schoenfeld (2019), which underscore the significance of cultivating students' ability to engage in logical reasoning and generate sound

mathematical arguments. The research is in accordance with the assumption that mastery of mathematical reasoning is crucial for pupils to effectively comprehend intricate geometric principles, such as congruent triangles. Schoenfeld, A. H. in 2019. Addressing the Challenges of Ensuring Mathematics Proficiency for Every Child: Considerations of Standards, Assessment, and Equality. The citation provided is from the Journal of Mathematical Behavior, the research is additionally positioned within the particular domain of reasoning and proof related to congruent triangles. The present study centers on the scholarly contributions of Usiskin (2018) and Senk (2020), who have extensively examined the theoretical framework pertaining to the instruction and acquisition of congruent triangle theorems. This theoretical framework recognizes the importance of congruence proofs in the field of geometry education and the difficulties that students may face in comprehending the formal structure and implications of these theorems.

An examination of the definition of quadrilaterals and their classification. The citation provided is in the format of an academic article from "The Mathematics Teacher" journal, In the year 2020, Senk, S. L. conducted a study. A retrospective analysis of mathematics education: An examination from a North American vantage point. The publication company known as Information Age Publishing. In this scholarly discourse, we shall go into the topic of errors that commonly occur in the realm of geometry reasoning and proof.

In order to enhance the theoretical foundation, the present work adds the perspective of errors in the realm of geometrical reasoning and proof. The research conducted by Harel and Sowder (2018) sheds light on the prevalent difficulties encountered by students in the field of geometry. The theoretical framework in question recognizes that errors can serve as indicators of students' cognitive processes and influences the development of interventions, such as the rubric implemented in the research. Harel and Sowder (2018) conducted a study. In the pursuit of attaining full insights into the learning and instructional aspects of proof, it is imperative to adopt a holistic approach. Springer is a renowned academic publishing company.

The present theoretical framework incorporates the overarching principles of mathematical reasoning while specifically examining congruent triangles, taking into account the potential challenges that students may face. This study provides a theoretical framework for comprehending the difficulties encountered by Asian students within a particular geometric setting. This understanding informs the creation of a rubric as a focused intervention aimed at improving instructional practices. Schoenfeld, A. H. in the year 2019. Ensuring Inclusive Mathematics Education: Examining Challenges in Standards, Assessment, and Equality. "The Mathematics Teacher" The present discourse aims to provide an overview of the historical development of mathematics education, focusing specifically on the North American. Harel and Sowder (2018) conducted a study. In the pursuit of attaining full insights into the learning and instructional aspects of proof, it is imperative to adopt a holistic approach. Springer is a well-known academic publisher that specializes in scientific, technical, and medical literature

2. Methodology

The study employed a quantitative research design and was conducted in a junior high school in Asia, in 2023. This design aimed to systematically investigate errors in the reasoning and proof skills of eighth-grade students in the context of congruent triangles within the Asian educational setting.

Participants: The participants in the study were 100 students from two classrooms (Class A and Class B) in the selected Students in Asia. Class A comprised students who were overall

proficient in mathematics, while Class B consisted of students who were not proficient in mathematics. The demographic information included 60 girls and 40 boys.

Measures: The Congruent Triangles Reasoning and Proof Test (CTRPT) was the primary measure used in this study. The test, comprising 12 items initially, was developed based on a theoretical framework categorizing nine types of errors in congruent triangle reasoning and proof. These errors were derived from existing literature and studies related to geometric reasoning and proof. The test format included multiple-choice questions, true or false items, short answer questions, real-world problems, and open-ended items.

Data Collection: Data were collected through the administration of the CTRPT during regular math classes. A total of 100 test sheets were distributed, and the same number of test sheets were collected. Among them, 99 test sheets were deemed valid after eliminating those with blank responses for all items. The test was designed to be completed within 50 minutes, and each participant was instructed to work independently.

Data Analysis: Quantitative and qualitative data analysis methods were employed. Quantitatively, a detailed item analysis was conducted to assess the performance of students on each item of the CTRPT. Qualitative data were obtained through semi-structured interviews with both students and teachers. The interviews aimed to explore the reasons behind the errors identified in the CTRPT. The qualitative data were analyzed to gain insights into the types of errors made by students and to cross-check and validate findings from the item analysis. The study utilized a rubric for evaluating congruent reasoning and proof, which encompassed deductive reasoning, verification and adjustment, and drawing-visualization-construction aspects.

3. Result and Discussion

This table outlines the major error types observed in the CTRPT (Congruent Triangle Reasoning and Proof Test) for five specific items. The errors range from a lack of understanding of essential theorems to difficulties in graphics processing and proof steps. Notably, item 5 specifically mentions confusion about irrelevant conditions in the graph.

Table 1: Major Error Types in CTRPT Test

Item	Major Error Types in CTRPT Test
Item 1	Did not understand the theorems (SSS, AAS, SAS, ASA, and HL) in essence.
Item 2	Difficulties in complex graphics processing. Errors in concrete proof steps.
Item 3	Lack of ability to understand and evaluate peers' proof process. Errors in establishing relations between congruent triangles and conclusions.
Item 4	Difficulties in complex graphics processing. Lack of self-adjustment and self-reflection consciousness.
Item 5	Standard graph set. Confusion about irrelevant conditions in the graph.

This table illustrates the distribution of responses for item one between Class A and Class B. Class A shows a higher number of correct choices (Choice C), indicating a better understanding of the concepts. Class B, on the other hand, has a higher frequency of incorrect choices (Choice A and Choice B).

Table 2: Response Distribution between Class A and Class B for Item One

Class #	Choice A	Choice B	Choice C (Correct)	Choice D
A	8	8	35	0
B	5	10	32	1

The table breaks down errors for item one, highlighting the second-level index, level, and specific errors associated with each choice. For example, in Class A, there were errors in applying the SSS theorem incorrectly to prove two triangles congruent (Choice A). This detailed breakdown provides insights into the specific misconception's students may have.

Table 3: Errors in Item One

Choice	Second Level Index	Level	Errors
A	Analysis and Abstraction	Informal	Applied SSS theorem incorrectly to prove two triangles congruent.
B	Analysis and Abstraction Representation and Transformation	Informal	Applied SAS theorem to incorrectly prove two triangles congruent.
D	Analysis and Abstraction	Informal	Applied HL theorem incorrectly to prove two triangles congruent.

This table categorizes the reasoning and proof levels in Classes A and B for item three. Class A demonstrates a higher level of rigor, with 35 students reaching the highest level, while Class B has a mix of informal, formal, and rigorous responses. This suggests variations in the depth of understanding and application of reasoning and proof concepts.

Table 4: Reasoning and Proof Level Distribution of Item Three in Classes A and B

Class #	Informal	Formal	Rigor
A	7	6	35
B	1	7	20
Total	8	13	55

Similar to Table 4, this table breaks down the reasoning and proof levels for item four. Class A shows a more balanced distribution across informal, formal, and rigorous levels, while Class B exhibits a higher number of formal responses. The differences between the classes highlight potential areas for improvement in understanding and applying reasoning and proof.

Table 5: Reasoning and Proof Level Distribution of Item Four in Classes A and B

Class #	Informal	Formal	Rigor
A	5	9	19
B	8	23	11
Total	13	32	30

The examination of the results of the Congruent Triangle Reasoning and argument Test (CTRPT) uncovers significant trends in students' comprehension of congruent triangle reasoning and argument. Table 1 presents a comprehensive overview of significant categories of errors observed in five distinct items. These errors encompass a wide range of topics, including misconceptions related to the fundamental theorem, difficulties encountered in graphics processing, and obstacles associated with self-reflection. Significantly, the fifth item highlights a lack of clarity regarding inconsequential graph circumstances, so identifying a specific domain that requires focused intervention. The response distribution presented in Table 2 demonstrates that Class A exhibits higher performance than Class B, suggesting a more comprehensive understanding of the fundamental concepts. Table 3 provides a more comprehensive analysis, elucidating certain inaccuracies observed in Class A, notably the misapplication of the SSS theorem. Upon examining Tables 4 and 5, it becomes evident that there are subtle distinctions between the groups in terms of reasoning and proof levels, with Class A constantly exhibiting a superior level of rigor. The results of this study indicate that there is a requirement for tailored assistance in Class B, with a particular emphasis on rectifying individual misunderstandings and enhancing the general level of comprehension in the domain of congruent triangle reasoning and evidence. The comprehensive comprehension of this subject matter enables educators to customize interventions in a manner that efficiently promotes enhanced outcomes in the crucial domain of geometric reasoning.

4.Conclusion

This research sheds light on the intricate landscape of congruent triangle reasoning and proof skills among Asian students, offering a comprehensive examination of the challenges faced by participants in comprehending and applying fundamental theorems. The study's scope, encompassing 100 participants across Asia, has revealed significant hurdles in multiple facets of engagement with congruent triangles. From confusion surrounding connotation and formal structure to struggles in graphic analysis and proof articulation, students demonstrated a nuanced array of difficulties. The introduction of a systematic rubric emerges as a valuable contribution, providing educators and researchers with a tool to assess and address specific areas of challenge highlighted in the study. The results from the Congruent Triangle Reasoning and Proof Test (CTRPT) further underscore these challenges, emphasizing the need for tailored assistance, particularly in Class B, to rectify individual misconceptions and elevate overall comprehension. By pinpointing specific error categories and distributing responses across different classes, the study enables educators to implement targeted interventions, thereby enhancing instructional strategies and curriculum development in the domain of geometric reasoning. As we move forward, the insights gleaned from this research serve as a foundation for refining educational approaches and fostering improved outcomes in congruent triangle reasoning and proof skills among Asian students.

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