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Students' Proportional Reasoning Level in Solving Missing Value Problems with GeoGebra Assistance

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Abstract

Proportional reasoning is the basis for understanding advanced mathematical concepts, but students in Indonesia still have difficulty in solving problems involving proportions and ratios. This study aims to describe the level of students' proportional reasoning in solving missing value problems with the help of GeoGebra. The research method used was qualitative with a case study approach, involving three students in class IX at one of the public junior high schools in Surabaya. The selection of subjects was based on mathematical ability, the same gender, and good communication skills. The research instruments included the researcher, mathematics ability test, proportional reasoning test, and interview. The results showed that students with high, medium, and low mathematics ability had reached level 2 in solving missing value problems using GeoGebra. The difference among the three students lies in the strategy used when solving the problem. This research has implications for students' proportional reasoning using GeoGebra.

Keywords: Reasoning, Proportional Reasoning Level, Missing Value Problem, GeoGebra

Abstrak

Penalaran proporsional merupakan dasar dalam memahami konsep matematika tingkat lanjut, namun siswa di Indonesia masih mengalami kesulitan dalam menyelesaikan masalah yang melibatkan proporsi dan rasio. Penelitian ini bertujuan untuk mendeskripsikan tingkat penalaran proporsional siswa dalam menyelesaikan masalah missing value dengan bantuan GeoGebra. Metode penelitian yang digunakan adalah kualitatif dengan pendekatan studi kasus, melibatkan tiga siswa kelas IX di salah satu SMP Negeri di Surabaya. Pemilihan subjek didasarkan pada kemampuan matematika, jenis kelamin yang sama, dan kemampuan komunikasi yang baik. Instrumen penelitian meliputi peneliti, tes kemampuan matematika, tes penalaran proporsional, dan wawancara. Hasil penelitian menunjukkan bahwa siswa dengan kemampuan matematika tinggi, sedang, dan rendah sama-sama telah mencapai level 2 dalam menyelesaikan masalah missing value menggunakan GeoGebra. Perbedaan di antara ketiga siswa terletak pada strategi yang digunakan ketika menyelesaikan masalah. Penelitian ini berimplikasi pada penalaran proporsional siswa dengan menggunakan bantuan GeoGebra.

Kata kunci: Penalaran, Level Penalaran Proporsional, Masalah *Missing Value*, GeoGebra

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Introduction

Reasoning is an important aspect in mathematical activities. Maher et al. (2023) states that one of the process standards in learning mathematics is reasoning. Reasoning is the capacity to reason logically from a stage of cohesive thought, deriving sound conclusions from the available data in accordance with predetermined guidelines (Sholihah & Aini, 2023). Babakr et al. (2019) argue that reasoning involving logic occurs at the formal operational stage, where at this stage students have thought about experiences beyond concrete experiences and think more idealistically, abstractly, and logically. In formal reasoning, reasoning is grouped into six types, namely: 1) conservation reasoning, 2) proportional reasoning, 3) probabilistic reasoning, 4) combinatorial reasoning, 5) correlational reasoning, and 6) variable control (Piaget & Inhelder, 2014). Of the six types of reasoning, proportional reasoning is one type of reasoning that needs to be developed at the secondary education level (Langrall & Swafford, 2000) because proportional reasoning measures understanding of rational numbers (Lamon, 2020). Proportional reasoning is often seen as ‘the cornerstone of basic arithmetic, number, and measurement concepts’ and ‘the foundation of algebra and other areas of higher mathematics’. Therefore, proportional reasoning is fundamental in the mathematical activities of middle grade students (Lamon, 2020; Tjoe & Torre, 2012).

Proportional reasoning skills are needed by every student, especially when solving problems related to the concepts of proportion and ratio, which is one of the test materials in the junior high school mathematics curriculum (Johar et al., 2018) and can help students in the world of work that requires proportional reasoning (Lamon, 2020). This reasoning helps students understand proportional relationships in a situation that shows invariance or a covariance and is solved using logical thinking (Nugraha et al., 2023). According to Supply et al. (2023), proportional reasoning is the ability to understand, construct, and use the multiplication relationship between two covariance measurements. Thus, proportional reasoning allows for complex understanding relating to proportions and ratios (Sari et al., 2023).

To know the extent of proportional reasoning of each individual, Langrall & Swafford (2000) divided proportional reasoning into four levels, namely level 0, level 1, level 2, and level 3. The division of these levels is based on the strategies used by students (Langrall & Swafford, 2000; Sari et al., 2023). Proportional reasoning levels can also describe a person's ability to solve proportional problems (Azhar et al., 2021) and measure their understanding of proportional concepts (Wahyuni & Prihatiningtyas, 2020). It aligns to Tjoe & Torre (2012), it is necessary to know the extent of students' proportional reasoning level and one way to find out is by using proportional reasoning assessment.

According to Tjoe & Torre (2012) proportional reasoning is one of the main focuses in mathematics assessment. These assessments are proportional reasoning problems which are divided into three types, namely missing value, numerical comparison, and qualitative prediction and comparison (Ahl, 2016; Johar et al., 2018; Tunç, 2020). Missing value problems are problems that provide three numerical information and then students are asked to find one unknown value (Nur & Sari, 2022; Prayitno et al., 2019). Meanwhile, the numerical comparison problem is a problem that looks for a relationship formed from two ratios (Tunç, 2020). As for qualitative prediction and comparison is a problem with comparing and predicting qualitatively (Tunç, 2020). Based on the results of research conducted by Tjoe & Torre (2012), at least 50% of proportional reasoning problems from three types of proportional reasoning problems taught in classes with national or international assessments are missing value problems.

The importance of proportional reasoning is not in accordance with the facts in the field, which reveal that the proportional reasoning of students in Indonesia is still relatively low. Based on the results of the average PISA mathematics score of Indonesian students of 366 points, illustrating that the average score of mathematics in Indonesia is below the world average score of 472 points (OECD, 2023). The score states that the mathematical reasoning aspect is the lowest level of skill than other skills and has an impact on students' proportional reasoning ability (Misnasanti et al., 2017; OECD, 2023). This statement is supported by data from the average results of the proportional reasoning ability test conducted on junior high school students in Bogor with an average score of only 48.46 (Yuliani et al., 2021). Another study also revealed that most of the proportional reasoning levels of junior high school students in Indonesia are still at level 1, and only one student has reached level 5 or multiplicative level (Putra et al., 2020). It shows that proportional reasoning requires students to perform complex calculations (Supply et al., 2023) and requires a long development process (Mardika & Mahmudi, 2021), meanwhile students still lack of mathematics basic skill, principle, and concept (Azis et al., 2023). It can be concluded that the condition of proportional reasoning in Indonesia is still concerning (Misnasanti et al., 2017; OECD, 2023; Putra et al., 2020; Yuliani et al., 2021).

One of the efforts in supporting students' proportional reasoning is designing proportional reasoning activities integrated by technology (Cuevas-Vallejo et al., 2023). The use of technology in mathematics activities can allow students to interact with various representations, facilitate simulation of realistic situations, and test their own results in an interactive virtual teaching environment (Cuevas-Vallejo et al., 2023). Hartiningrum et al. (2023) stated if the way people learn, teach, and access information for mathematics activity has changed significantly as a result of technology. One of the technology use is GeoGebra (Cuevas-Vallejo et al., 2023).

GeoGebra is one of the software that can be used to support students' proportional reasoning (Restrepo-Ochoa et al., 2023). GeoGebra is an educational mathematics software program that conceptualizes and utilizes dynamic mathematics and is often used as a teaching and learning tool from high school to college level (Ziatdinov & Valles, 2022). In one study, it was found that by using GeoGebra, students who initially had no ideas related to the concepts of similarity and proportionality were helped to construct the definitions of similarity and proportionality properly (Restrepo-Ochoa et al., 2023). It means that GeoGebra can be used as a tool for measuring students' proportional reasoning in solving mathematics problem (Lutfi et al., 2024).

Nevertheless, there are still few studies that focus on the level of proportional reasoning assisted by GeoGebra, particularly in Indonesian school. Whereas using technology, one of which is GeoGebra, can support students' proportional reasoning (Cuevas-Vallejo et al., 2023; Restrepo-Ochoa et al., 2023) which can be seen through the level of proportional reasoning (Vanluydt et al., 2021). Based on the explanation, this research aims to describe the level of proportional reasoning of junior high school students in solving missing value problems using GeoGebra software.

Method

This is case study research with a qualitative approach. The subjects of this study was selected using purposive sampling, which is determine the subject by the differences (Faizien et al., 2023) of mathematical abilities, namely high, medium, and low, and was done by considering good communication skills and the same gender. The instruments used in this research are the researcher himself as the main instrument and supporting instruments, namely the Mathematics Ability Test (MAT), Proportional Reasoning Test (PRT), and semi-structured interviews. The stages of this research are divided into three, namely preparation, implementation, and data analysis. In preparation stage consists compiling research indicator (see Table 1) preparation of research instruments, instrument validation, and instrument readability testing.

Table 1. Indicator of Proportional Reasoning Level

Level	Indicator	Sub-Indicator
0 – Non-Proportional Reasoning	Solving missing value problems intuitively or with random visual assistance	Solving missing value problems intuitively
		Solving missing value problems using GeoGebra visual assistance
	Solving missing value problems using any number concept, operation, or strategy	Solving missing value problems using any number concept, any operation, and any strategy after exploring GeoGebra
	Unable to determine multiplicative relationships in missing value problems	Unable to determine the existence of a multiplicative relationship in missing value problems
1 – Informal Reasoning	Solving missing value problems using pictures, models, or manipulation	Solving missing value problems using the GeoGebra exploration page to understand the problem
		Solving missing value problems using manipulation and a model obtained using GeoGebra

Level	Indicator	Sub-Indicator
	Solving missing value problems using qualitative comparison	Solving missing value problems by making qualitative comparisons within GeoGebra
2 – Quantitative Reasoning	Solving missing value problems by calculating based on unit values	Solving missing value problems by calculating based on unit values
	Solving missing value problems using numerical calculations	Solving missing value problems by applying formulas and numerical calculations using GeoGebra
3 – Formal Reasoning	Solving missing value problems by identifying invariants and covariants	Solving missing value problems by identifying invariants and covariants
	Solving missing value problems using equivalent fractions between variables in proportion form	Solving missing value problems using equivalent fractions between variables in proportion form
	Solving missing value problems using the cross-product rule between variables in proportion form	Solving missing value problems using the cross-product rule between variables in proportion form

In implementation stage, MAT was administered to one class IX, three research subjects were selected, PRT was administered, and Interview was conducted. The problem used in the PRT is a missing value problem that uses a value comparison context integrated with GeoGebra Classroom (see Figure 1). This instrument is equipped with a place for student exploration to find solutions to the problems given. Students can use sliders and other features provided on GeoGebra (see Figure 2).

INFORMASI

Dalam rangka meningkatkan perekonomian masyarakat Jawa Timur, Dinas Kebudayaan dan Pariwisata Provinsi Jawa Timur memiliki proyek untuk membangun lokasi wisata baru di dataran tinggi. Sisa lahan dari pembangun itu, akan dibangun taman yang dipasang rumput sintesis dengan ukuran 100 cm x 50 cm. Dengan terbatasnya budget, maka kontraktor tersebut berencana membeli 30 rumput sintesis untuk dipasangkan di Taman. Namun, ternyata sebagian sisa lahan tersebut mengalami longsor sehingga harus dilakukan pengukuran ulang. Akibatnya, ukuran taman yang baru diubah dengan memperkecil panjang taman menjadi $\frac{1}{2}$ kali ukuran awal dan lebarnya menjadi 3 kali lebih besar dari ukuran semula.

Figure 1. PRT Instrument in GeoGebra

Translate: To improve the economy of the people of East Java, the East Java Provincial Culture and Tourism Office has a project to build new tourist sites in the highlands. The remaining land from the construction will be built in a park installed with synthetic grass with a size of 100 cm x 50 cm. With a limited budget, the contractor plans to buy 30 artificial turfs to be installed in the park. However, it turned out that some of the remaining land had landslides, so they had to re-measure. As a result, the size of the new garden was changed by reducing the length of the garden to 1/2 the original size and the width to 3 times the size of the original garden.

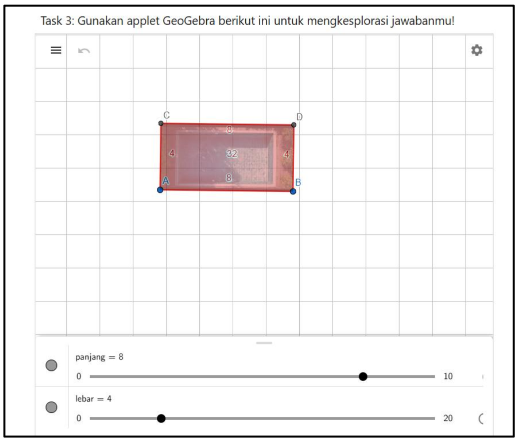

Figure 2. Display of GeoGebra

Lastly, in data analysis will be carried out with three stages referring to Creswell & Cresswell (2023), namely data reduction, data presentation, and conclusion drawing. Data from the mathematics ability test results will be grouped based on the calculation results referring to table 1. Meanwhile, the results of the proportional reasoning data analysis will be adjusted to the reference indicators shown in table 2. Interview data will be transcribed and coded to identify consistent themes related to students' reasoning. The results from each data source will then be compared to gain a deeper understanding of the students' proportional reasoning abilities.

Table 2. Mathematics Ability Classification

Score	Category
$Score \leq \overline{X} - SD$	Low
$\overline{X} - SD < Score < \overline{X} + SD$	Medium
$Score \geq \overline{X} + SD$	High

(Arikunto, 2018)

Description
Average (X) = 1/2 (Maximum Score + Minimum Score)
Standard Deviation (SD) = 1/6 (Maximum Score – Minimum Score)

Result and Discussion

Before the subjects were selected to be given PRT, the students were given MAT with questions in the form of prerequisite material from proportion and ratio material. Three students were selected out with one student in each category. These students were chosen based on the diversity of their mathematical abilities, categorized as high, medium, and low. This classification was essential to observe how students with different levels of understanding respond to the PRT intervention. The results of the MAT are presented in the following table.

Table 3. MAT Results

Mathematics Ability Category	Student Codes	Gender
High	HS	Male
Medium	MS	Male
Low	LS	Male

Table 3 represents the MAT results based on Table 2. To analyze PRT and interview data, it uses a coding system. The code includes letter “H” describes about mathematics ability “High” and followed by letter “S” refers to student. Each selected student represents a unique profile that enables diverse insights into how mathematical ability influences problem-solving using PRT. This categorization also supports the validity of the study by ensuring a balanced representation of different ability levels. Moreover, focusing on male students in this study allows for more controlled comparisons without gender as a varying factor.

Proportional Reasoning Level of High Mathematical Ability Student

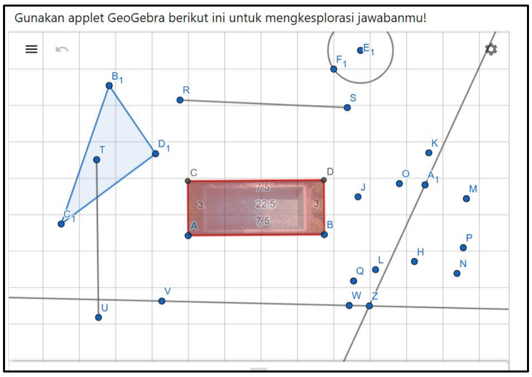

Figure 3. HS’s Exploration on GeoGebra

Based on the Figure 3, HS appears to use various features in GeoGebra to understand the problem situation. In his interview, HS admitted that he used GeoGebra to interpret the length, width and area of the garden. It helped him to found the meaning of problem. In line with the opinion by Ziatdinov & Valles (2022) that using GeoGebra when solving mathematical problems, can increase student confidence. This indirectly shows that with GeoGebra, students' thoughts regarding possible solutions are validated by GeoGebra. Moreover, the dynamic nature of GeoGebra allowed HS to manipulate the figures freely, giving him a clearer insight into the relationships between dimensions (İBİLİ, 2019). He also mentioned that visual feedback from the software made him feel more certain about his calculations. As a result, GeoGebra functioned not only as a computational tool, but also as a thinking partner in the problem-solving process (Ziatdinov & Valles, 2022).

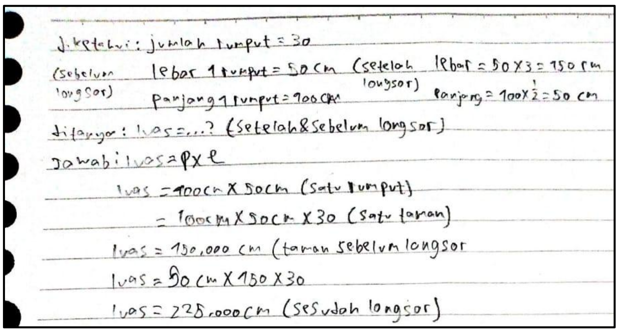

Figure 4. HS’s Answer

Figure 4 shows HS can solve the problem using unitizing, which found its area for one synthesized grass then multiplied it by 30. HS has also used the right formula and performed correct numerical calculations. According to Sari & Mampouw (2019), if the strategy used when solving proportional reasoning problems is unitizing, using the correct formula, and correct numerical calculations, then the student's proportional reasoning level is at level 2 - Quantitative reasoning. The use of GeoGebra to understand the problem is one of the steps students use before students use numerical calculations (Langrall & Swafford, 2000). This shows that HS understands the relationship between multiplicative comparison and area. He connected spatial understanding with arithmetic reasoning to derive the final answer. The accuracy in HS's calculation also reflects a solid grasp of measurement units and proportional relationships.

Proportional Reasoning Level of Medium Mathematical Ability Student

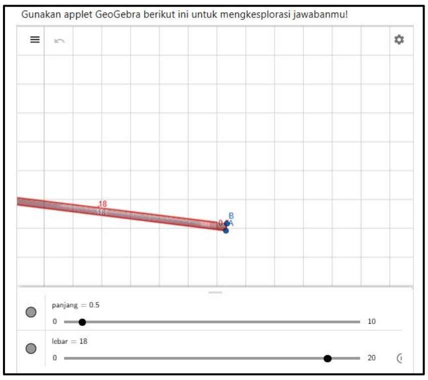

Figure 5. MS's Exploration

Based on Figure 5, MS utilized GeoGebra as an exploration tool to understand the problem. MS also claimed in her interview, that he shifted the sliders to find patterns that fit the problem conditions. This shows that GeoGebra allows students to experiment, create strategies, make conjectures, and infer mathematical properties (Waiandt et al., 2019). Waiandt et al. (2019) also added that GeoGebra provides a tool for developing and exploring proportional reasoning from interdisciplinary perspective. In this case, MS demonstrated flexibility in adjusting variables to seek meaningful relationships between quantities. His engagement with the dynamic features of GeoGebra indicates active reasoning and persistence in solving the missing value problem. This aligns with the notion that digital tools can support students in visualizing abstract mathematical relationships more concretely (Adelabu et al., 2019).

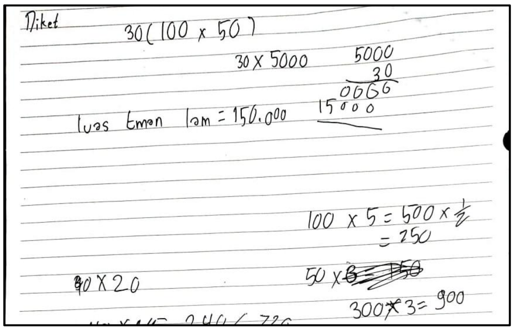

Figure 6. MS's Answer

From using GeoGebra to understand the problem, MS switched to writing down how to solve the problem on paper as shown in Figure 6. Although MS did not write in an orderly manner, it appears that MS also used a unitizing strategy. MS first found the value of the area of one patch of synthetic grass, multiplied it by 30, then compared it. In the solution, MS also modelled the arrangement of artificial turf in the new garden, which is 5 sideways and 6 downwards. This was also explained by MS in the interview session. The strategy used by MS has been explained by Sari et al. (2023) who mentioned, one of the strategies used by students when solving proportional reasoning problems is to use a model to understand the problem, before performing calculations. According to the strategy used by MS, it can be categorized that her proportional reasoning level is at level 2 (Langrall & Swafford, 2000).

Proportional Reasoning Level of Low Mathematical Ability Student

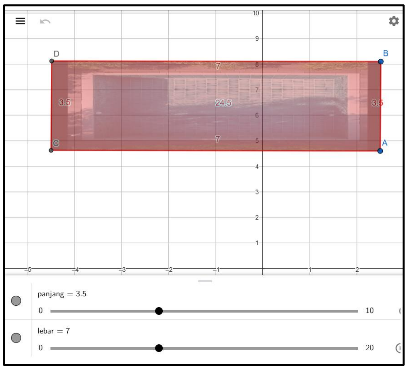

Figure 7. LS's Exploration

As shown in Figure 7, LS also used GeoGebra to explore the meaning of the problem. Similar to MS, before writing down the solution of the problem, LS also played with the sliders in GeoGebra to find the appropriate length and width patterns. Nugraha et al. (2016) suggested that the use of images can help understand the initial concepts of comparison before entering more complex procedures. Especially if the image can be explored by students independently through GeoGebra. (Zulnaidi et al., 2020). This interaction indicates that LS used visual and manipulative representations as a scaffold for his reasoning process. Despite being categorized in the low ability group, LS demonstrated initiative in experimenting with dynamic features to seek appropriate answers. This suggests that with appropriate digital support, students with varying abilities can still engage meaningfully in mathematical reasoning (Lutfi et al., 2024).

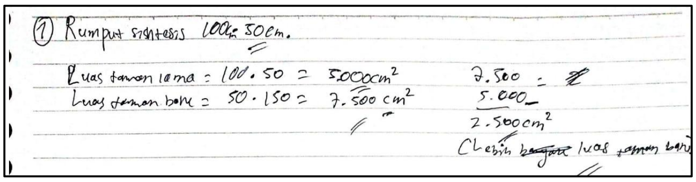

Figure 8. LS's Answer

From LS's answer in Figure 8, it can be seen that LS did not realize the difference between the size of the artificial turf area and the garden area. LS assumed that one artificial turf has the same size as one garden. The challenges LS faces indicate that LS is unable to accurately identify problem (Azizah & Khoiri, 2022). This affected the calculation result obtained by LS. Nevertheless, LS used the rectangular area formula correctly using unitizing strategy. The use of this strategy shows that LS's level of proportional reasoning is level 2 proportional reasoning (Sari et al., 2023). However, LS's misconception caused a mismatch between the interpretation of quantities and the actual context of the problem. This reveals the importance of conceptual understanding before engaging in procedural strategies (Azis et al., 2023). Despite errors in reasoning, LS's attempt demonstrates emerging skills that need further guidance.

Overall, the three subjects demonstrated the use of similar strategies, utilizing GeoGebra to understand the given problem (see Table 4). In addition, they also performed calculations by calculating the size of each old and new garden and then comparing them. This indicates that all three used the unitizing strategy, which is at level 2 – Quantitative Reasoning. The same level among the three subjects indicates that they had similar understanding of the given problem (Setyaningrum & Mampouw, 2020), especially since they were provided with GeoGebra to aid in understanding the problem (Lutfi et al., 2024). Another factor is that they designed a solution plan using the same method they had previously used or been taught by their teacher in class (Faseha et al., 2021).

Table 4. The Differences of Subjects' Strategy

	HS's Strategy	MS's Strategy	LS's Strategy
GeoGebra	He used GeoGebra to interpret the length, width and area of the garden. It helped him to found the meaning of problem.	He shifted the sliders to find patterns that fit the problem conditions.	Before writing down the solution of the problem, LS also played with the sliders in GeoGebra to find the appropriate length and width patterns.
Calculation	HS can solve the problem using unitizing, which found its area for one synthesized grass then multiplied it by 30. HS has also used the right formula and performed correct numerical calculations.	Although MS did not write in an orderly manner, it appears that MS also used a unitizing strategy. MS first found the value of the area of one patch of synthetic grass, multiplied it by 30, then compared it. In the solution, MS also modelled the arrangement of artificial turf in the new garden, which is 5 sideways and 6 downwards.	LS did not realize the difference between the size of the artificial turf area and the garden area. LS assumed that one artificial turf has the same size as one garden.
Proportional Reasoning Level	Level 2 - Quantitative Reasoning	Level 2 - Quantitative Reasoning	Level 2 - Quantitative Reasoning

Conclusion

This study examined students' proportional reasoning levels when solving missing-value problems with GeoGebra. The analysis revealed that all three participants effectively utilized GeoGebra's visualization tools to interpret problems and employed unitizing strategies to find solutions, demonstrating achievement of Level 2 Proportional Reasoning according to established frameworks. These findings highlight how dynamic geometry software can serve as a cognitive scaffold, helping students transition from additive to multiplicative thinking - a crucial milestone in mathematical development.

The study makes two important contributions to mathematics education. First, it provides empirical evidence that GeoGebra can effectively support proportional reasoning development, particularly through its interactive visualization capabilities. Second, it identifies unitizing as a key strategy emerging when students work with digital tools, suggesting that technology may encourage particular problem-solving approaches. These insights enrich our understanding of how digital manipulative influence mathematical thinking processes in middle school students.

Based on these findings, two recommendations emerge. For classroom practice, teachers should incorporate GeoGebra regularly when teaching proportionality, especially for real-world context problems where visualization enhances understanding. For future research, scholars should investigate whether similar benefits occur with other digital tools (like Desmos or virtual manipulative) and across different proportionality topics (such as scaling or similarity). Such studies could further clarify technology's role in developing higher-level mathematical reasoning.

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