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EXPLORRING THE FUNDAMENTAL CONSEPTS OF QUADRILATERAL FORMULAS THROUGH ORIGAMI TO ENHANCE STUDENTS UNDERSTANDING OF FORMULA DERIVATION

Windy Handayani[1], Fanden Batara Damanik[2], Fasya Nabilah Putri[3], Filza Anati Ibna[4], Nathan Abyansyah[5], Kairuddin[6]
[1-6]Program Studi Pendidikan Matematika, Universitas Negeri Medan, Indonesia
Email Correspondence: lala.fasya04@gmail.com

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Abstract
This study examines the impact of origami-based learning on students' conceptual understanding of deriving quadrilateral area formulas and explores their perceptions of this instructional approach. Employing a mixed-methods design, the research involved 18 tenth-grade students in Medan, Indonesia. Quantitative data were collected through pretest and posttest assessments and analyzed using the Wilcoxon Signed-Rank Test and N-Gain to determine learning improvement. Qualitative data were obtained through semi-structured interviews and analyzed thematically to capture students' experiences and perspectives. The findings reveal a statistically significant increase in students' conceptual understanding ($Z = -3.724$, $p < 0.001$), supported by a medium N-Gain score of 0.62 and a large effect size ($r = 0.88$). Students reported that origami activities enhanced their ability to visualize geometric transformations and facilitated deeper comprehension of formula derivation. However, some students encountered minor technical difficulties during the folding process. Overall, data triangulation confirms that origami-based learning is an effective, engaging, and meaningful alternative to traditional memorization-based geometry instruction.
Keywords: *Education, Mathematics, Consepts, Students*

INTRODUCTION

The base of science is mathematic and important to science develovment which has an important position in all element of our life (Nugraheni & Marsigit, 2021). All the aspect, from simple up to hard problem, of course cannot separate from science and mathematic. According to Pasandaran & Suciati, (2021), the core of mathematics lies in the use of representations; consequently, it is essential for students to grasp the specific form of each representation associated with a mathematical concept to achieve full mastery. There is a lot of mathematician from the past until now, like Archimedes (geometry/ calculus), Phytagoras (theorem), Persian Scholar Al-Khawarizmi (Algebra), etc. A research by Nur et al., (2021) showing how the mathematics exists in indonesia's education. Keyword mathematic has been used most frequently in science journal scoop. It mean mathematic in indonesian is very intense and may impactfull to indonesian's young generation. Mathematic is a subject which has been learned since first grade in elementary school.

In mathematics, creativity is both a key factor and a supporting element that can determine how easy or difficult it is for someone to learn the subject. Base on paper of research by Muzaini, (2023), cause of many definion of creativity, they have clasificated in to some perspective. 1) Proceses or creative stage, 2) Characteristic of creative and the products, 3) Creative personality, and 4) Cognitive processes underlying creative activities. In Geometry, especially at flat structure (square, rectangle, parallelogram, rhombus, kite and trapezium), is a one of most popular and important branch of mathematics. Unfortunately, Geometry at Senior High School in indonesian, often still focuses on memorising formulas without a deeper understanding of the origins (derivation) of those formulas. The impatc of that's memorising is made studends depending on formulas without understanding of connection of those geometry stucture.

The determination of quadrilateral hierarchies is based on logical reasoning regarding specific geometric attributes, such as equal side lengths, the presence of parallel sides, the measures of opposite angles, and diagonal characteristics including their lengths, orthogonality, and how they bisect one another. In practice, this classification is distinguished into inclusive and exclusive approaches. The inclusive approach places the concept within a hierarchical structure where a trapezoid is broadly defined as a quadrilateral having at least one pair of parallel sides, thereby encompassing more specific forms. Conversely, the exclusive approach defines a trapezoid more strictly as a quadrilateral that has exactly one pair of parallel sides, which automatically separates the trapezoid from the family of parallelograms (Orman & Sevgi, 2025). Recent studies also emphasize that students' understanding of quadrilateral hierarchies is closely related to their ability to reason about class inclusion and properties of shapes, which often develops through visual and transformational experiences in geometry learning (Fujita & Jones, 2021; Susanti, Rahman, & Hidayat, 2022). These findings highlight the importance of instructional approaches that explicitly connect geometric properties with hierarchical classification systems.

The ability to understand the process of deriving or formulating a formula is a key indicator of deep conceptual mastery, as it enables students to grasp the logic behind the formation of a formula rather than merely memorizing it (Barana, 2021). This procedural understanding equips students with the capacity to apply, analyze, and even formulate new solutions independently. Theoretically, this competency aligns with the higher cognitive levels in Bloom's Taxonomy, which encompass the aspects of analysis (C4), evaluation (C5), and the creation stage (C6), where students are able to reconstruct knowledge in a more meaningful way (Technology, 2021).

Origami is an art form that originated in Japanese culture and involves folding a piece of paper into intricate shapes and designs (Marji et al., 2023). Throughout the primary and secondary education years, mathematics is treated as a foundational yet challenging subject that students often perceive as overly abstract (Hibi, 2022). This perception frequently leads to a reliance on rote memorization rather than genuine comprehension. Many educators still define mathematical success as the immediate and accurate application of formulas, rules, and calculation methods (Info, 2025). Consequently, traditional teaching models often focus on presenting pre-packaged information, where students are expected to follow standardized procedures to reach singular correct answers, prioritizing the mechanical use of learned content over deep conceptual understanding.

Incorporating origami into mathematics education enhances children's spatial skills, fosters geometric reasoning, and improves their overall academic performance in geometry (Habeeb, 2025). Through the act of folding, the resulting creases and intersection points in origami serve to demonstrate various geometric properties, including sides, angles, vertices, edges, and planar surfaces (Torres, 2024). The use of origami enhances students' comprehension of geometric terminology and concepts while simultaneously strengthening their spatial visualization abilities (Meloni et al., 2021).

Although various studies have explored the use of origami in geometry instruction, as well as the importance of conceptual understanding of plane figure formulas, there remain several gaps that form the basis for this study. First, there is a lack of focus on the formula derivation process. Previous studies, such as those conducted by Habeeb (2025) and Torres (2024), have primarily highlighted how origami can enhance spatial skills and the recognition of geometric shapes in general. However, few studies have specifically investigated how paper-folding activities can be used as a tool to guide students in discovering and deriving formulas for the areas of quadrilateral plane figures such as rectangles, parallelograms, rhombuses, and kites and in understanding the relationships among these formulas.

Second, there is a gap between theoretical potential and empirical evidence. Theoretically, origami is considered to have the potential to bridge abstract geometric concepts with concrete experiences (Meloni et al., 2021; Hibi, 2022). However, robust empirical evidence regarding the effectiveness of this method specifically in improving understanding of formula derivations for quadrilateral concepts remains limited. Most studies still focus on affective aspects such as student motivation or perception, without quantitatively measuring improvements in conceptual understanding through controlled pretest-posttest designs.

Given these gaps, this study aims to address them by analyzing the impact of origami-based learning on students' conceptual understanding of deriving the formula for the area of a quadrilateral, while also exploring their perceptions of this learning experience through a mixed-methods approach.

This study aims to analyze the effect of origami-based learning on students' conceptual understanding in deriving quadrilateral area formulas based on pretest and posttest results. In addition, this study aims to explore students' perceptions of the implemented learning approach, particularly in terms of their understanding, learning experiences, and the effectiveness of the method, through interviews.

RESEARCH METHOD

This research has held in Friday, March 13, 2026 at 10.30 AM up to 12.00 AM. The subject of this research is eighteen students from ten's Grade in MAN 2 Medan, North. The 18 students will not be identified by their real names, but will be represented by the initial 'R' followed by a number. For example, R1 for student 1, R2 for student 2, and so on.

Mixed methods research is the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration. A mixed methods study would involve mixing within a single study; a mixed method program would involve mixing within a program of research and the mixing might occur across a closely related set of studies (Nagpal et al., 2020).

RESULTS AND DISCUSSION

Data Description Pretest dan Posttest

Table 1. Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Pretest Score	18	300	700	597.2222	116.59662
Postest Score	18	225	1000	769.4444	185.81212
Valid N (listwise)	18				

Based on Table 1, the data description shows that the number of respondents (N) was 18 students for the pretest and posttest scores. In the pretest score, the minimum score obtained by students was 300 and the maximum score was 700, with an average of 597.22 and a standard deviation of 116.60, indicating a relatively moderate data distribution. Meanwhile, in the posttest score, the minimum score increased to 225 and the maximum score reached 1000, with an average of 769.44 and a standard deviation of 185.81, indicating higher data variation compared to the pretest. In general, there was an increase in the average score from the pretest to the posttest, indicating an improvement in student learning outcomes after the treatment was given.

Normality test for Pretest and Posttest

Table 2. Test of Normality

	Kolmogorov-Smirnov			Shaphiro-Wilk		
	Statistic	df	Signification	Statistic	df	Signification
Pretest Score	0.248	18	0.005	0.798	18	0.001
Posttest Score	0.249	18	< 0.001	0.857	18	0.001

Based on Table 2, the results of the normality test using the Kolmogorov-Smirnov and Shapiro-Wilk test indicate that the pretest and posttest data are not normally distributed. In the pretest score, the significance value of the Kolmogorov-Smirnov test is 0.005 and the Shapiro-Wilk test is 0.001, both of which are less than 0.05. Similarly, in the posttest score, the significance value of the Kolmogorov-Smirnov test is less than 0.001 and the Shapiro-Wilk test is 0.001, which is also below 0.05. Thus, it can be concluded that both data do not meet the assumption of normality, so the further statistical analysis used is a non-parametric test, namely the Wilcoxon Signed-Rank test.

Table 3. Second Test of Normality

Variabel	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pretest Score		18	0,005	0,798	18	0,001
Posttest Score	0,248	18	<0,001	0,857	18	0,011

According to Table 2, the Shapiro-Wilk significance value for the pre-test data is 0.001 and for the post-test data is 0.011. Both values are less than 0.05, so it can be concluded that the pre-test and post-test data are not normally distributed. The same results are also shown by the Kolmogorov-Smirnov test, with a significance value of 0.005 for the pre-test and < 0.001 for the post-test.

As the assumption of normality was not met, the hypothesis test for the difference between the pre-test and post-test was conducted using the non-parametric Wilcoxon Signed-Rank Test. This test is a suitable alternative to the parametric paired-sample t-test when the data are not normally distributed (Keilmuan et al., n.d.).

Hypothesis Testing

Having established that the pre-test and post-test data were not normally distributed, hypothesis testing was carried out using the non-parametric Wilcoxon Signed-Rank Test. This test was used to assess whether there was a significant difference between the students’ pre-test and post-test results following origami-based instruction. The hypotheses proposed were as follows:

- H_0: There was no significant difference between the students’ pre-test and post-test scores.

- H_1: There is a significant difference between the students' pre-test and post-test scores.

Decisions were based on the significance value (two-tailed) at a significance level of $\alpha = 0.05$. If the significance value was < 0.05, H_0 was rejected and H_1 accepted.

The results of the Wilcoxon Signed-Rank Test are presented in Table 4.

Table 4. Result of test Wilcoxon Signed Rank Test

Decription	N	Mean Rank	Sum of Ranks	Z	Asyimp. Sig (2- tailed)
Negative Ranks (Posttest < Pretest)	0	0.00	0.00	-3,724	< 0.001
Positive Ranks (Posttest > Pretest)	18	9.50	171.00		
Ties (Posttest = Pretest)	0				

According to Table 4, all 18 pupils showed an improvement in their scores. The calculated Z-score was -3.724, with a significance level (two-tailed) of < 0.001. As the significance level is less than 0.05, H_0 is rejected. Consequently, there is a significant difference between the pupils' pre-test and post-test scores following origami-based instruction.

N-Gain Analysis

To measure the effectiveness of origami-based learning in improving students' conceptual understanding, a Normalised Gain (N-Gain) calculation was performed using the same formula employed in the study conducted by Triyono et al., (2024):

$$\boldsymbol{N\text{-}Gain} = \frac{\text{Score Posttest} - \text{Score Pretest}}{\text{Score Maksimum} - \text{Score Pretest}}$$

The categories of effectiveness based on N-Gain are:

- High : $g > 0,7$
- Medium : $0,3 \leq g \leq 0,7$
- Low : $g < 0,3$

The results of the N-Gain calculations for all pupils are presented in Table 5.

Table 5. Result of N-Gain

Category	Range N-Gain	Frequency	Persentation(%)
High	$g > 0,7$	6	33,33
Medium	$0,3 \leq g \leq 0,7$	10	55,56
Low	$g < 0,3$	2	11,11
Sum		18	100

The average N-Gain obtained was 0.62, which falls into the moderate category. This indicates that origami-based learning improves students' conceptual understanding with a moderate level of effectiveness. Nevertheless, as many as 6 students (33.33%) achieved the high category, suggesting that this method is highly effective for the majority of students. The two students in the low category were likely influenced by internal factors such as a lack of focus during the activity or initial difficulties in understanding geometric concepts, which were also reflected in the interview results.

Interview Results

Following the learning process involving students and teachers, the students were then interviewed. The interviews focused on their feedback regarding the material that had been presented. The interview results were grouped into three categories, which were established in line with the objectives of the previous research.

The first category is conceptual understanding. In response to questions tailored to this category, pupils were able to explain the relationships between shapes derived from quadrilaterals. As one student replied: "I do understand, because it turns out all those formulas are related, as the kite formula is actually half of a triangle, isn't it." and also, "And also, the parallelogram has the same formula, and the trapezium is half of a parallelogram." From the answers given by these students, it can be concluded that the lessons taught have been well received. This is evident from the fact that they were able to explain the formulas for shapes derived from quadrilaterals.

The second category is the learning experience. Students felt enthusiastic and motivated because they gained a clear understanding of the origins and relationships between the formulas relating to quadrilaterals. This is evident from a student's response: "Yes, I do understand it better now. I really do understand it much better. Of course, the calculations are easier now that I understand what the basic concepts are like." Because the material was presented as simply as possible, some students felt it helped them.

Thirdly, regarding the effectiveness of the method. The effectiveness of the method means that the method used has distinct advantages over previous methods that have also been employed. Its relevance to this study lies in how effective the method used is, as determined from interviews with the students. In response to the interviewer's question, "From our activities, what do you feel has helped you most in understanding the concept?", the students replied: "It's the triangle, actually, because before that I was quite confused; with this formula, it was like, 'where does the half come from?', and 'how can there be a half of a half?' It turns out that it comes from the division of the triangle, so it becomes the formula ½".

Data Triangulation

To gain a more comprehensive understanding of the effectiveness of origami-based learning, a triangulation was carried out between quantitative data (N Gain) and qualitative data (interview results). The aim of this triangulation was to examine the consistency, complementarity and potential discrepancies between the two types of data (Zuryani, 2023).

Quantitatively, the average N Gain of 0.62 falls within the moderate category, with 88.89% of students falling within the moderate to high categories. This indicates that the majority of students experienced a significant improvement in understanding. These findings are consistent with the results of the interviews, which showed that students were able to explain the process of deriving the formula using the analogy of folding paper.

"*I now understand why the area of a parallelogram is equal to the base times the height. When you fold the paper, the shape can be transformed into a rectangle." (R3, N Gain height) "Whereas before I just knew the formula for the area of a rhombus ½ × d1 × d2 — now I understand it through the rearrangement of origami pieces." (R7, N Gain, moderate)*

These findings confirm that the improvement in post-test scores is not merely the result of rote learning, but reflects conceptual understanding developed through the concrete experience of folding paper.

The quantitative data provides an overview indicating that learning effectiveness falls into the moderate category. However, the interview data explains why not all students achieved a high N Gain. Some students with a low N Gain described the challenges they faced:

"I was a bit confused when we were folding things up, because there were so many steps and I lost track." (R12, Low N Gain)

"It would be better if the teacher just gave us the formula straight away; I'm not really keen on folding activities." (R15, Low N)

These findings complement the quantitative results by demonstrating that internal factors (difficulty following procedures, learning style preferences) can influence the effectiveness of the method. Thus, although the method is statistically significantly effective, individual success is still influenced by student characteristics.

The variation in N Gain scores, ranging from low to high, is also explained by the interviews. Students with high N Gain scores generally reported positive learning experiences and felt that the visual elements were helpful:

""I like folding activities. It helps me remember better because I'm actually holding the paper." (R2, High N)

Conversely, students with moderate and low N Gains were more likely to mention technical challenges, such as the pace of instruction or a lack of precision when folding. This information is important for improving the implementation of the method in the future, for example by providing step-by-step guidance sheets or dividing students into small groups.

Overall, triangulation indicates that quantitative and qualitative data converge in demonstrating that origami-based learning yields significant and meaningful improvements in understanding. Qualitative data not only reinforces the statistical results but also provides an in-depth explanation of the factors influencing the success of the implementation. This mixed-methods approach yields more comprehensive conclusions than if only one type of data had been used.

DISCUSSION

The Effect of Origami on the Understanding of Formula Derivation

Before the implementation of origami-based learning, the pre-test results revealed that many students experienced substantial difficulties in understanding fundamental quadrilateral concepts. A number of students were unable to correctly identify quadrilateral shapes, as evidenced by responses such as "*cube*" and everyday objects like "*table*" and "*window*". This indicates a fundamental misconception, particularly the inability to distinguish between two-dimensional and three-dimensional geometrical representations.

In addition to conceptual misunderstandings, notable errors were observed in basic computational tasks. For example, when asked to determine the area of a square with a side length of 8 cm, several students provided incorrect answers such as 16 or 32 instead of 64. Similar patterns of error were found in problems involving rectangles, rhombuses, and kites, especially in the omission of the one-half (½) factor in formulas involving diagonals. These findings suggest that students relied heavily on rote memorisation, with limited understanding of the structural basis underlying the formulas. This is consistent with previous findings that students often experience difficulties when they are introduced directly to formulas without understanding how those formulas are derived (Salsabila et al., 2024).

Furthermore, students' responses reflected misunderstandings in conceptual reasoning. For instance, when asked, "Why is height required when calculating the area of a parallelogram?", some students responded that "because the right and left sides have different heights" or "because it is like a slanted square". These responses indicate that students have not yet understood height as the perpendicular distance between two parallel sides, but instead rely on misleading visual interpretations of the shape. This further highlights the gap between students' conceptual understanding and their visual perception of geometric figures.

This procedural tendency was further confirmed by students' explanations, which frequently included statements such as "because that is the formula." Such responses reflect a surface-level approach to learning, where formulas are treated as isolated rules rather than as logical consequences of geometric relationships. Collectively, these findings highlight a critical gap between procedural fluency and conceptual understanding, underscoring the need for instructional strategies that promote meaningful learning.

Following the implementation of origami-based learning, a substantial improvement in students' understanding was observed, as reflected in the post-test results. Most students were able to accurately solve problems related to the area and perimeter of quadrilaterals, including squares, rectangles, parallelograms, rhombuses, and kites. Compared to the pre-test, students' responses became more consistent and mathematically coherent.

This improvement is particularly evident in students' ability to correctly compute standard results, such as 64 cm^2 for a square and 72 cm^2 for a rectangle, as well as in their consistent application of the one-half (½) factor in diagonal-based formulas an aspect that frequently led to errors in the pre-test. The reduction of such errors indicates a shift from fragmented procedural knowledge towards integrated conceptual understanding. In other words, students were no longer merely recalling formulas, but were able to interpret and apply them based on underlying geometric principles.

This understanding is further reflected in students' written responses in the post-test, which indicate that they began to recognise the origin of the formulas. For example, when asked, "Why can the area of a rhombus be calculated using the formula ½ × diagonal 1 × diagonal 2?", one student explained that the first diagonal can be interpreted as the length and the second diagonal as the width of a rectangle. Since the rhombus can be seen as half of the rectangle formed through this representation, its area is expressed as ½ × diagonal 1 × diagonal 2. This explanation demonstrates that the student was able to connect the formula to an equivalent geometric representation and the transformation process experienced during the origami activity, indicating not only procedural accuracy but also conceptual understanding of how the formula is derived.

Understanding the derivation of formulas is widely recognised as a key indicator of conceptual mastery and is closely associated with higher-order thinking skills (C4–C6) in Bloom's Taxonomy (Technology, 2021). At the C4 (Analysing) level, students demonstrated the ability to decompose geometric structures and identify relationships between different components of quadrilateral formulas. This is evident from their improved performance in both pre- and post-test comparisons, as well as from their ability to articulate connections during the learning process. This ability further reflects the use of logical thinking processes, such as classification and correlation, which function as cognitive tools in mathematical problem solving (Loengson & Limjap, 2003, as cited in Syamsuddin, 2019).

At the C5 (Creating) level, students engaged in reconstructing geometric forms by transforming one shape into another through origami activities. This process reflects an active construction of knowledge, where students reorganise existing information into new configurations. Meanwhile, elements of C6 (Evaluation) were observed when students justified and verified the correctness of the formulas they derived, indicating an emerging capacity for critical mathematical reasoning. Such exploratory learning activities encourage students to observe, manipulate, and construct their own understanding, which contributes to deeper conceptual learning (Jiang, n.d.).

However, it is important to note that this study did not employ a specific instrument designed to measure each level of Bloom's Taxonomy. Therefore, these interpretations should be understood as indicative of higher-order thinking processes rather than definitive claims of mastery at each level.

Coorelations Between Quadrilateral Concepts

The improvement in students' conceptual understanding is further supported by a direct comparison between pre-test and post-test responses. In the pre-test phase, students tended to perceive each quadrilateral formula as an isolated entity that needed to be memorised independently. There was minimal evidence of relational thinking or structural awareness between different geometric forms.

In contrast, the post-test results indicate a significant shift in perspective. Students not only demonstrated higher accuracy in calculations but also showed an increased ability to recognise relationships between shapes. For example, they were able to explain how a parallelogram can be transformed into a rectangle, or how the formulas for rhombuses and kites are fundamentally related to the area of a rectangle through the use of diagonals. This finding is consistent with previous research indicating that students are able to recognise relationships between geometric properties and classify shapes hierarchically (Van de Walle, 2001, as cited in Syamsuddin, 2019).

This finding addresses a well-documented limitation in traditional geometry instruction, where students are often required to memorise formulas without understanding their interconnections. In reality, recognising the hierarchical relationships among quadrilaterals—such as viewing a square as a special case of a rectangle, or understanding how a parallelogram can be derived from a rectangle—is essential for developing a coherent understanding of geometry (Rahimi, 2026).

Origami-based learning provides a concrete medium through which these abstract relationships can be visualised and experienced directly. Through folding, cutting, and rearranging paper, students actively engage in transforming one geometric shape into another. This type of activity allows students to manipulate abstract concepts in a hands-on manner, which supports deeper conceptual understanding and mathematical reasoning (Jiang, n.d.). For instance, when deriving the area formula of a parallelogram, students can physically manipulate the shape by cutting and repositioning a triangular section to form a rectangle. This transformation demonstrates that the area remains invariant, thereby justifying the formula base × height.

Similar transformations were applied to rhombuses and kites. By rearranging these shapes, students observed that their areas can be expressed as half the product of their diagonals, which conceptually aligns with the area of a rectangle. This hands-on experience enables students to move beyond memorisation and towards relational understanding. This finding supports the view that the use of concrete and contextual learning media helps students connect abstract mathematical concepts with real experiences, thereby improving their conceptual understanding (Salsabila et al., 2024). Quantitatively, this conceptual development is reflected in the relatively high average N-Gain score (0.62) and the large effect size. Notably, the most significant improvements were observed in post-test items that required students to understand transformations and derive formulas, rather than simply recall them.

Thus, origami-based learning does not merely enhance students' ability to remember formulas, but fundamentally restructures their understanding of geometry. It facilitates the development of a connected knowledge system, in which mathematical concepts are no longer perceived as isolated facts, but as interrelated components of a coherent whole.

Students' Perceptions of Origami Lessons

Pupils consistently reported that paper-folding activities helped them to visualise the process of deriving formulas, which they had previously merely memorised. Statements such as "I now understand why the area of a parallelogram is equal to the base times the height, because the fold can form a rectangle" (R3, High Gain) demonstrate that origami bridges abstract concepts with concrete experiences. This finding is consistent with previous studies suggesting that hands-on and contextual learning can enhance students' conceptual understanding by connecting mathematical ideas to tangible experiences (Salsabila et al., 2024).

This indicates that origami does not merely support procedural knowledge, but also facilitates deeper conceptual visualisation, which is essential in geometry learning. The positive perception aligns with the quantitative results, where all students experienced improvement, reflected in a large effect size ($r = 0.88$).

However, a small number of students reported difficulties in following the folding steps, describing them as too fast or complex. This suggests that the effectiveness of origami-based learning depends on adequate instructional scaffolding. Teachers should therefore provide clear, step-by-step guidance and adapt the pace of instruction to accommodate diverse learning needs

Implications and Limitations of the Study

The findings of this study offer both practical and theoretical contributions to mathematics education. Practically, origami can serve as an effective alternative approach for teaching quadrilateral formulas through discovery-based learning, allowing students to understand not only how formulas work but also how they are derived. In addition, origami activities utilise simple and accessible materials, making them feasible for implementation in various educational contexts.

From a theoretical perspective, this study supports the role of concrete and exploratory learning in promoting conceptual understanding of geometric relationships. It highlights how transforming abstract mathematical ideas into physical experiences can facilitate meaningful learning and higher-order thinking.

Despite these contributions, several limitations should be acknowledged. The relatively small sample size ($n = 18$) limits the generalisability of the findings. The short duration of the intervention also makes it difficult to evaluate long-term retention of students' understanding. Furthermore, the absence of a control group restricts the ability to attribute improvements solely to the origami-based intervention. Future research is therefore recommended to involve larger samples, longer implementation periods, and comparative experimental designs.

Synthesis of Qualitative and Quantitative Findings

The integration of quantitative and qualitative findings reveals strong convergence. Quantitatively, the Wilcoxon test showed a significant improvement ($p < 0.001$), with a mean N-Gain of 0.62 (moderate category) and a large effect size ($r = 0.88$). Qualitatively, students with high N-Gain demonstrated the ability to explain the derivation of formulas through folding processes, while students with lower gains highlighted technical challenges as barriers to learning.

This convergence strengthens the validity of the findings, as both data sources consistently indicate that origami-based learning enhances conceptual understanding. Moreover, the qualitative data provide deeper insight into how and why the improvement occurred, particularly through visualisation and active engagement in the learning process. This result is also supported by previous research emphasising that understanding relationships among geometric concepts plays a key role in developing meaningful mathematical understanding (Elbehary et al., 2023).

Overall, the mixed-methods approach provides a comprehensive perspective, showing that origami-based learning is effective not only in improving students' performance but also in transforming their understanding of mathematical concepts into a more connected and meaningful structure.

CONCLUSION

Origami-based learning has been shown to significantly improve pupils' conceptual understanding of deriving the formula for the area of quadrilaterals. This is demonstrated by the Wilcoxon test ($p < 0.001$), a mean N-Gain of 0.62 (moderate category), and a large effect size ($r = 0.88$). Students not only achieved higher post-test scores but were also able to explain the origin of the formula through paper-folding analogies—for example, how a parallelogram and a rhombus can be transformed into a rectangle. This hierarchical understanding of flat shapes demonstrates that origami bridges abstract concepts with concrete experiences, thereby making students' geometric knowledge more structured and meaningful.

The students' response to this method was also positive. They reported that it provided visual support and found the learning more enjoyable because they were actively involved in the discovery process. Nevertheless, technical challenges such as the pace of instruction require attention to ensure all students can follow effectively. Overall, origami is effective as an alternative approach to teaching geometry that emphasises understanding the derivation of formulas, rather than mere memorisation, whilst fostering an interactive and meaningful learning experience.

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