

Research Article

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Author for correspondence:

Duaa Zahi Melhem

✉ DRDuaaMelhem@gmail.com

✉ Yarmouk University/ Jordan



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Improving Geometric Thinking Skills Through a Multisensory-Based CRA Framework in Students with Learning Difficulties and Various Sensory Preferences

Duaa Zahi Melhem^{ID}, Ali Mohammad Al Zoubi^{ID}, Mamoon Mohammad Al-Shannaq^{ID}, Amani Saleh Hasan Raiyan^{ID}, Hussein Melhem^{ID}

Abstract

Background/Objective. This study aimed to assess the effectiveness of a multisensory approach based on the CRA framework in enhancing geometric thinking skills among fourth-grade students with learning difficulties in mathematics. It examined the relationship between sense preferences and performance and investigated how interactions among those senses impact the students' performance.

Materials/methods. A quasi-experimental approach was established to achieve the objectives of this study. The study sample consisted of 196 students, divided equally into a control and an experimental group. The effect of the intervention upon students' geometric thinking was measured using a pre- and post-test. Additionally, a questionnaire was used to gather data on sensory preferences.

Results. The results of this study revealed that students who learned using the multisensory approach based on the CRA framework achieved higher performance (mean = 147.22) than those who studied traditionally (mean = 49.78), and these differences were statistically significant at the significance level ($\alpha = 0.05$), and the study reveals the predictive value of sensory preferences; it has shown that visual learning is strongly associated with high performance, and it reveals the subtle interactions between sensory preferences.

Conclusion. The effectiveness of the multisensory approach based on the CRA framework was shown to improve geometrical thinking skills, and there is a relationship between sensory preferences and students' performance, as well as a relationship between the interaction of different sensory preferences and students' performance.

1. Introduction

Geometry forms the most accessible and intuitive gateways for children entering the world of mathematics, owing to its inherent connection with natural perceptual modes. Children primarily base their learning processes on direct observation, with the forms and structures of objects capturing their attention the most. The regularity and symmetry of shapes are often associated with their beauty, motivating children to associate such shapes with beauty; for instance, when a child wants to express the regularity of shapes, they may describe a shape as "beautiful" (Hejný, 1993).

Recognizing this essential relationship, the National Council of Teachers of Mathematics (NCTM) (2000) not only underlines the central role of geometry in facilitating the resolution of diverse mathematical problems but also in serving as a cornerstone for developing comprehensive mathematical understanding. Engagement with geometric concepts promotes essential competencies such as reasoning, critical thinking, and mathematical representation skills (Jones, 2003).

Mason (1997) and Mayberry (1983) examine geometric thinking as a set of mental activities that involve sequential and progressive stages of development; the individual cannot advance to a higher level without mastering the previous one, which builds on prior knowledge and experiences. Van Hiele's levels of geometric thinking are widely recognized. These levels include:

- **Visualization:** Recognizing shapes without perceiving their properties, like identifying a square without realizing that all its sides are equal.
- **Analysis:** Gaining simple knowledge of the properties of geometric objects, like the equality of opposite angles.
- **Informal reasoning:** Ability to trace the connection between different geometrical figures and find their similarities and differences.
- **Abstraction:** Much more than just identifying properties and introducing a way of proof through axioms, postulates, and definitions.
- **Rigor:** Ability to work with abstract geometric concepts, understand complex proofs, and present several geometrical systems different from Euclidean geometry (Clements & Battista, 1992; Crowley, 1987).

Students often face difficulties in this area despite the importance of learning geometry. Such problems depend on the quality of education and inappropriate educational scaffolding. Usually, the teacher relies on pictures in textbooks and verbal explanations or makes geometrical drawings on the board that are incorrect (İbili et al., 2019; Widyasari & Mastura, 2020).

A lack of conceptual understanding of geometric concepts and elements, for example, when the students struggle to identify the characteristics of geometric shapes, has previously led to difficulties like dyslexia, which limits students' ability to accurately read geometric instructions or interpret geometric symbols and textual descriptions associated with shapes. or dyscalculia, which limits students' ability to understand quantitative relationships between shapes, such as comparing areas or perimeters or even understanding the relationships between side lengths and angles of geometric shapes. Exhibiting negative attitudes toward learning geometry, like feelings of boredom or being part of a social environment that does not value the importance of learning, were identified as the factors leading to difficulties in learning geometry (Butterworth, 2005; Gogo et al., 2021).

Regardless of the causes and sources of disability, there must be some form of justice in making education accessible to all, regardless of their physical or mental differences. Comprehensive curricula focus on making education inclusive for both students with difficulties and their peers

because they view diversity as a natural and beneficial condition (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2005).

Learning difficulties in mathematics have been addressed in many studies (e.g., Geary, 2004; Rousselle & Noël, 2007), which describe them as a set of challenges that prevent students from successfully performing mathematical tasks, following arithmetic procedures, understanding mathematical concepts, and facing visual challenges, particularly in the field of geometry. These difficulties are attributed to several factors, including working memory, processing speed, and numerical sense. Barut and Retnawati (2020) highlighted the challenges students face in learning geometric topics:

- Difficulty in representing the properties of two-dimensional and three-dimensional geometric shapes: for example, understanding the relationship between a square (as an example of a two-dimensional shape) and a cube (as an example of a three-dimensional shape), where the student may not grasp that each cube contains six squares.
- Difficulty in solving geometric tasks, especially when modifying the positions of geometric shapes: for example, a student may struggle to apply what they have learned about triangles in tasks where the triangle is inverted.
- Difficulty viewing geometric shapes from different angles: A student may be unable to draw a cube from the top corner instead of drawing it from the front, as they are accustomed to doing.
- Difficulty in analyzing geometric shapes and calculating their area: A student may find it challenging to break down a pyramid into small triangles and rectangles to determine its surface area.
- Weakness in deductive thinking skills: A student may struggle to analyze a given geometric problem, like being unable to find the length of the third side in a right triangle when given the lengths of the other two sides, which limits their ability to accurately apply the Pythagorean theorem.

Several strategies have been developed to address various learning difficulties, including the multisensory strategy. According to the studies conducted by the National Institute for Child Health and Human Development (NICHD), multisensory strategies have been proven very effective in teaching children with learning difficulties. These were activating visual, auditory, kinesthetic, and tactile senses to meet the varied needs of all students in learning, like a variety of teaching aids that may be helpful in the learning styles of visual learners, with educational films. In addition, auditory and visual memory and kinesthetic learning in hands-on learning activities with touch improve their learning (Multisensory Teaching Methods, 2024).

The role of human senses in cognitive processes is evident, as sensory experiences significantly shape an individual's thoughts. Each sense contributes to the formation of ideas in the mind, and sensory perception plays a key role in how ideas are developed. These ideas concern the sensory input from which they emanate: colors are seen, sounds are heard, flavors are tasted, and smells are smelled via olfaction. This interaction between the senses and the mind leads to cognitive constructs based on sensory information, like perceptions of size, shape, movement, and stillness. Most of these mind constructs come from the visual and tactile senses, further sealing the role of sensory input within the molding of human thought. In this light, diversity of senses acts as one of the most vital foundations toward the advancement of cognitive functions (Baker, 2019; Gazioğlu & Karakuş, 2023; Khasawneh, 2024). Several sensory-based instruction methods have been developed over time. They include:

- **Grace Fernald Method:** Stresses advanced learning using kinesthetic, visual, and auditory senses (Widiamoksa, 2019).

Orton-Gillingham Method: This method, established in the early 20th century, focuses on improving reading skills phonetically by incorporating multisensory learning into the learning process (Orton, 1966).

- **Stern Method:** Also known as the Stern-Bohm Method, this model relies on the incorporation of different senses in boosting learning outcomes (Stern, 2016).

- **Carbo Method:** targets the visual and kinesthetic senses to enhance memory and conceptual understanding (Sewell, 2001).

- **Writing for Writing Model:** utilizes writing activities to enhance reading skills (MacArthur et al., 2008).

- **Slingerland Method:** integrates multisensory to enhance learning. The approach that the Slingerland Method focuses on is usually systematic and structured (Lovitt & DeMier, 1984).

Briefly, this can be implemented in teaching by specializing in various learning styles. Audio learners rely on sound-oriented approaches: listening to tapes, rhythmic changes, and the use of musical instruments. In such learners, teachers should focus on clear and fluent communication, use audio equipment (e.g., speakers and recordings), and discuss and question in interactive sessions to enable better learning of concepts. As for the kinesthetic learners, whose mode of learning involves much hands-on activity, the teaching methodologies should hence include practical exercises (e.g., experiments, role-playing, and group projects to engage them). The more physically engaged these students are in terms of writing, reading, and class activities, the more attentive they will be and the more they will retain information for a longer time. On the other hand, the visual learner learns more through lessons that include videos, demonstrations, and the integration of body expressions. The integration of tools like digital boards, diagrams, and visual aids will help them understand and grasp information. Training in these styles will also adopt teaching methodologies to suit these kinds of learning styles and offer a more interactive and friendly environment for all students (Itagi & D'Mello, 2019).

The techniques of multisensory teaching enhance learning by making a student active in several dimensions. These methods encourage the learner to gather information about a task and hyperlink new ideas to prior knowledge. It enables learners to understand the logical processes that require solving problems; therefore, learners acquire problem-solving skills. It also develops the power of nonverbal reasoning, whereby the relationship among different ideas can be acquired by students in a far better way. Eventually, it will help to understand such complicated ideas and remember them for future recollection (Taljaard, 2016).

On the other hand, the Concrete-to-Representational-to-Abstract (CRA) framework follows three stages: the concrete stage, which involves hands-on materials; the representational stage, which involves visual aids; and the abstract stage, which uses symbolic representations (Watt et al., 2015).

Students with learning difficulties in Jordan face many challenges. The main issue is a lack of attention to their sensory preferences. This leads to poor achievement in mathematics. These students often have difficulty engaging with traditional learning that does not meet their unique needs. Therefore, there is an increase in innovative strategies to meet the needs of these students. Procuring a comprehensive and flexible learning environment promotes participation and increases educational efficiency. This study aims to fill the gap in existing literature, which is not sufficiently focused on geometric thinking through a multisensory approach based on the CRA framework. The research will analyze and understand the relationship among various sensory preferences, investigate how these preferences interact and support one another, and highlight those preferences that significantly affect student performance. Accordingly, this study seeks to answer the following questions:

- How does a multisensory approach based on the CRA framework affect geometric thinking skills among fourth-grade students with learning difficulties?
- Which sense has the most significant impact on geometric thinking performance?
- How do interactions between different senses influence students' performance in geometric thinking?

2. Literature Review

Multisensory education strategies have been studied in numerous settings, and the evidence has supported the use of this approach as an effective method for improving learning outcomes for students with varied difficulties. Green (2009) conducted a quasi-experimental study on the East Coast to explore the effectiveness of using multisensory teaching strategies in improving math achievement for fourth- and fifth-grade students with learning difficulties in mathematics. The sample comprised 12 students, and tests were carried out both before and after the intervention to measure outcomes. The results showed that the strategy had a positive effect on improving students' mathematical achievement.

In this perspective, Waters and Boon (2011) carried out an experimental study in Georgia to examine the effectiveness of TouchMath, a multisensory strategy, in completing 3-digit subtraction problems related to money and regrouping by secondary students with mild intellectual difficulties. The case study focused on a small-scale group of three students to develop these students' subtraction abilities through the TouchMath intervention program. The findings revealed a notable improvement in the students' ability to perform 3-digit subtraction in monetary contexts. However, following the withdrawal of the intervention, the students faced some difficulties sustaining performance, producing mixed results in terms of long-term retention.

Many authors in the literature have discussed multisensory within Arab countries as well. Eissa and Al Huseini (2013) conducted the quasi-experimental study in Egypt to explore the efficacy of using multisensory education strategies in teaching mathematical concepts among students with mild mental difficulties, based on a highly limited sample of 10 participants, with an equal division into a control and an experimental group, taking pre- and post-tests for measuring change. These findings indicated that the strategy had a positive effect on enhancing students' mathematical performance.

On the other hand, Hood (2014) conducted a quasi-experimental study in New Jersey aimed at establishing the efficacy of using multisensory teaching strategies in improving addition operation skills among students with mathematics learning difficulties. The sample for the study included 8 students, followed by the conduction of a test to assess the children's understanding of additional facts. The results showed that the strategy had a positive effect on improving students' addition skills.

Seminal contributions have been made by Krishna (2017), who conducted a quasi-experiment in India on the adoption of multisensory teaching strategies to improve fraction, triangle, and ratio skills among hearing-impaired students. The sample used was 38 students, divided into a control group and an experimental group. The pre- and post-tests were implemented, and the results showed that the strategy had a positive effect on improving students' skills.

Delport (2021) conducted a quasi-experimental study in Africa to examine the effectiveness of applying multisensory teaching strategies in enhancing students' skills in mathematical statistics. The sample size was 98 students, comprised of a control group of 43 and an experimental group of 55. Mathematical statistics were measured by tests. The findings revealed a significant positive effect of the multisensory strategy on improving students' performance in mathematical statistics.

A study by Gori et al. (2024) investigated, through a quasi-experimental design, the efficacy of multisensory teaching strategies to enhance geometric thinking skills in Italian children with difficulties in math learning. In this study, 87 students were divided into a control and an experimental group. A test assessing the understanding of three-dimensional geometric shapes was administered. The findings indicated that a multisensory strategy was effective in improving students' performance.

Regarding studies related to the CRA framework. AL-Salahat (2022) conducted a quasi-experimental study in Saudi Arabia to investigate the effectiveness of the CRA framework in teaching the perimeter of geometric shapes to students with learning difficulties. The study involved an experimental group of 8 students from 4th and 5th grades, who were assessed using specially designed tests. The findings indicated that the CRA framework was effective in improving the students' ability to calculate the perimeter of geometric shapes. Additionally, the students retained the acquired skills for three weeks after the intervention.

Kaya and Yildiz (2023) conducted a single-case study in Turkey to investigate the effectiveness of the CRA framework in teaching basic arithmetic skills to a student with learning difficulties. The findings indicated the effectiveness of the CRA framework in improving arithmetic skills. Furthermore, the student retained the acquired skills for four weeks post-intervention.

3. Methodology

The methodological approach can be summarized in the four steps: data collection, data preparation, the Mann-Whitney U test, and random forest analysis. Figure 1 shows the methodological steps that were used in this study, consisting of four main steps to systematically analyze the data:

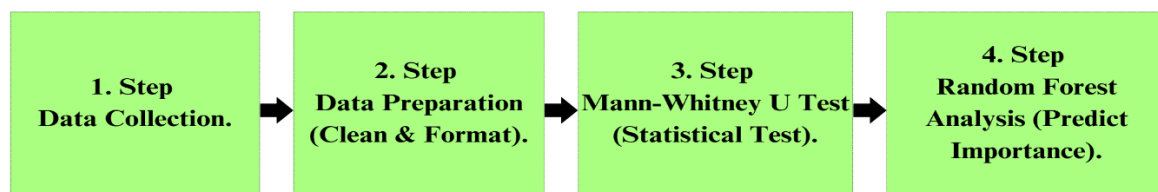


Figure 1. Steps of the methodological approach

3.1. Data Collection

This study used a quasi-experimental design to achieve its objectives. Data were collected from 196 fourth-grade students who were officially diagnosed as having learning difficulties in mathematics by a specialist working in a resource room within private schools in Irbid. The sample was selected based on recent diagnostic reports. Confirming struggles with learning difficulties. This is reflected in their low academic performance in mathematics. They came from middle-class families, did not have severe family problems, and equally received material and psychological support to provide equal opportunities for them to obtain a good education. In this research, there are two groups: the experimental group, which receives instruction through the strategy for nine weeks, and the control group, which is taught using conventional methods. Quantitative data were collected through a geometrical thinking test to measure skills (identifying geometric shapes, describing geometric properties, spatial visualization, geometric reasoning, and abstract geometric concepts), and a questionnaire was redesigned to assess sensory preferences.

3.2. Data Preparation (Clean & Format)

To achieve the study goals, the geometric unit for the fourth grade was analyzed. The main geometrical terms and concepts were identified, including line, ray, point, straight line, straight segment, angle, right angle, acute angle, straight angle, obtuse angle, vertex of the angle, and sides of the angle. Measuring and drawing angles using a protractor; the concept of parallel and intersecting lines includes two parallel lines, two intersecting lines, and two perpendicular lines. Finally, this unit covered networks, three-dimensional shapes, and parallelograms. Concepts of symmetry, such as symmetry, axis of symmetry, and reflection, which included the axis of reflection, image, and reflection, were also explored.

Referring to the study of Khan and Khan (2021), lessons were restructured against the three guiding principles: concrete, representational, and abstract. Following the development phase, the content was then cross-checked with special education experts and piloted on an exploratory sample.

Table 1 presents the three main steps in learning: concrete, representational, and abstract, which could easily be used in geometry lessons with students in the fourth grade, specifically for those who have learning difficulties. Each step plays a critical role in learning about geometric concepts fully, and for students to move progressively from concrete aspects into more abstract thinking. The following is a detailed explanation of these stages:

- **Concrete Stage:** During this initial stage, the individual learner manipulates concrete objects (e.g., geometric blocks and models) to investigate basic ideas about geometry. Manipulation in this manner uses physical objects so that students have an easily attainable, concrete understanding of shapes, lines, and angles that are important for a student who may struggle with abstract thought. The hands-on activities are key to this because they safely engage students in exploring the properties of shapes and relationships (e.g., the straw construction of polygons) and help students visualize and construct physically to make learning more interactive. Real-life applications (e.g., geometry walks), where students identify shapes around them, help bridge what goes on inside the classroom to the outside world by reinforcing understandings through observation and application, which enhances the first level of geometric thinking (visualization).

- **Representational Stage:** Proceeding from the concrete manipulative to the visual, this stage focuses on drawing and diagramming of the shapes explored. This "seeing" stage enables the student to visually represent his or her understanding, which is important in internalizing concepts in geometry. Visual aids, like posters and digital images, provide the resources to represent complicated relations (e.g., the various kinds of angles: acute, obtuse, and right; or parallel and perpendicular lines). Students develop more sophisticated understandings when abstract ideas are presented in various forms. Graphic organizers (e.g., Venn diagrams) enhance the analytical and informal deduction geometric thinking levels.

- **Abstract Stage:** The last stage involves the student being introduced to the symbolic geometric language, where he learns the relation between entities by using mathematical notation. This is an important transition because, further on, the student will get involved with geometry in more complex cognitive processes. In word problems, students practice their knowledge in more realistic situations, inviting them to produce deep reflections about geometric relations and measurements. For example, they can solve a problem by calculating the area of a shape or analyzing angles. Reflection and discussion are part and parcel of this stage since they nurture students to share their reasons for thinking about a concept in a particular manner. The students also benefit from peer learning since, as they present their work to their colleagues, they, in turn, cement their understanding of concepts, which enhances the abstraction and rigor levels of geometric thinking.

Table 1. Steps for designing a lesson according to a multisensory approach and CRA framework

Concrete	Representational	Abstract
This is the "mathematical model" stage, in which many different types of educational information and scaffolds are provided to support conceptual understanding.	This is the "seeing" stage, where images are used to represent mathematical ideas.	This is the "symbolic" stage in which actual symbols for the mathematical idea are used.

3.2.1. Statistical Thinking Test

Building on earlier studies (e.g., Crowley, 1987), a mathematics geometric skills test in the multiple-choice format was redesigned to measure various aspects of geometric thinking. The measured skills will involve the following:

- **Identifying Geometric Shapes:** The ability to recognize and name the basic geometric shapes, like circles, triangles, squares, and more complex polygons.

- **Describing Geometric Properties:** Knowing the properties and attributes of the different geometric shapes, like angles, sides, and symmetry.

Spatial Visualization: To perceive forms or spatial models and mentally manipulate them, one must know geometric transformations involving rotation, reflection, and translation.

- **Geometric Reasoning:** Logically correct formulation in solution to a geometric problem, determination of unknown angles, solution to problems involving side lengths, and relationships among various geometric configurations.

- **Abstract Geometric Concepts:** Knowledge of higher-level concepts in geometry, e.g., theorems and proofs, and application of abstract reasoning in solving complicated geometrical problems.

The validity of the test was verified by presenting the test in its initial form and the skills it measures to a group of arbitrators consisting of 10 specialists in the specialties of special education, mathematics curricula, and teaching methods. They expressed their opinions on the suitability of the paragraph for the skill to which it belongs, the language's integrity, and the phrase's clarity. The arbitrators indicated that the elements of the tool are appropriate and sufficient to achieve the study's objectives. Therefore, the test in its final form consisted of 30 paragraphs, distributed among its five skills.

Utilizing SPSS, a sample of the responses from 50 students outside the main sample selected for this study was analyzed to determine the difficulty and discrimination coefficients of the items in the test. The outcome revealed that the items' difficulty coefficients ranged from 0.32 to 0.83, whereas the discrimination coefficient ranged from 0.65 to 0.87. Accordingly, these values conform to the acceptable range for difficulty and discrimination parameters as recommended by (Crocker & Algina, 1986).

To ensure the reliability of the test, the internal consistency method was used by applying the Kuder-Richardson-20 (KR-20) equation, and a coefficient of 0.82 was obtained. It means that the test is highly reliable and internally consistent (Kuder & Richardson, 1937).

3.2.2. Sensory Preferences Questionnaire

Referring to the study of Reid (1987) and the website (VARK model), a questionnaire was redesigned to measure students' sensory preferences. The validity of the questionnaire was verified by presenting its initial form to a group of arbitrators consisting of 10 specialists in the fields of mathematics, curricula, teaching methods, and learning difficulties. They expressed their opinions on

the suitability of the phrase for the field to which it belongs, the correctness of the language, and the clarity of the phrase. The arbitrators indicated that the questionnaire elements were appropriate and sufficient to achieve the study objectives. Therefore, the final version of the questionnaire consisted of thirty statements, each aligned with one of the five senses. These statements were structured in a table with five columns to represent different sensory preferences. To ease data analysis, a binary coding system was followed, so students indicated their sensory preferences by marking '1', while their non-preferred ones were marked as '0'.

To ensure the reliability of the questionnaire, the reliability coefficient was calculated using the internal consistency method according to the Kuder-Richardson-20 (KR-20) equation. Its value reached 0.81, which is a value that indicates that the questionnaire has a high degree of reliability and internal consistency (Kuder & Richardson, 1937).

3.3. Mann-Whitney U Test

To analyze the impact of the multisensory approach based on the CRA framework on students' geometric thinking skills, the Mann-Whitney U test was used to compare the post-test scores between the experimental and the control groups. The test helped determine whether the performance of the two groups was significantly different.

3.4. Random Forest Analysis (Predict Importance)

After reviewing Ronaghan's (2018) study, the final step of the analysis used a random forest algorithm to assess the importance of different sensory preferences and interactions between them in predicting students' post-test performance. This machine learning technique assesses the importance of features by creating multiple decision trees and analyzing the weight and inaccuracy of the nodes. The random forest model is based on this equation:

$$v_{ij} = w_j C_j - w_{\text{left}(j)} C_{\text{left}(j)} - w_{\text{right}(j)} C_{\text{right}(j)}$$

4. Results

The Mann-Whitney test was used to answer the first question: How does a multisensory approach based on the CRA framework affect geometric thinking skills among fourth-grade students with learning difficulties?

Table 2 shows that there are statistically significant differences ($\alpha = 0.05$) attributed to the teaching method in all dimensions and in the total score. The differences were in favour of those who were exposed to teaching using the multisensory strategy:

- **Recognition of Geometric Shapes (Level 1):** By using the mean ranks of 128.19 versus 68.81 and a Mann-Whitney U value of 1892.000, it proves that the post-test result significantly favours the students taught with the multisensory strategy. The involvement of several senses during the learning process enhances the ability of the student to recognize and identify the shapes of geometry. This finding confirms previous studies (e.g., Eissa & Al Huseini, 2013; Green, 2009), which indicated that the use of multisensory approaches enhances development in mathematical recognition.

- **Understanding Geometric Properties (Level 2):** At this level, the mean ranks for students in the multisensory strategy group were 122.63, while those assigned to the traditional method group had mean ranks of 74.37, with a U value of 2437.500. This indicates that the students who worked with the multisensory approach came away better informed about the properties of geometric shapes. The finding is supported by earlier works on similar studies by Hood (2014) and Gori et al. (2024), respectively, where such an aspect, too, was noted; multisensory learning does yield better comprehension of abstract mathematical ideas.

- **Spatial Visualization (Level 3):** In spatial visualization, too, the multisensory group outperformed the traditional method group with a mean rank of 129.56 for the former against 67.44 for the latter, with a U value of 1758.000. Spatial visualization is an important aspect in solving geometric problems, and the finding here indicates that multisensory strategies lead students to create better mental images of shapes and manipulate them more effectively. Krishna (2017) also reported similar gains in spatial reasoning among students with difficulties while on multisensory education.

- **Geometric Reasoning (Level 4):** The mean rank was 130.77 for the multisensory group against the 66.23 obtained for the other group, with a Mann-Whitney U value of 1640.000, reflecting better performance in geometric reasoning. Geometric reasoning here refers to the derivation of logical conclusions from geometric properties, and these results here imply that multisensory strategies potentially enhance higher order thinking in this sphere.

- **Abstract Geometric Concepts (Level 5):** The greatest difference in achievement was in the comprehension of abstract geometric ideas. For the multisensory teaching group, the mean rank was perfect at 138.50; for the traditional method group, it was 58.50, with a U value of 882.000. This impressive result underlines how multisensory teaching enables students to learn even very abstract and complicated geometric concepts, which may be exceedingly difficult to teach by traditional methods.

- **Overall Geometric Skills:** The results further confirm that the post-test results of overall geometric skills were with a U value of 27.500, having mean ranks of 147.22 for multisensory and 49.78 for traditional, thus showing that multisensory learning is effective in enhancing mathematical performance at all levels of geometric thinking.

Table 2. Results of the "Mann-Whitney U Test" to determine the significance of the differences between the mean ranks on the geometric thinking test.

Dimension	Group	N	Mean Ranks	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z Value	Significance Level
Post Recognition of Geometric Shapes (Level 1).	Control Group	98	68.81	6743.0	1892.0	6743.00	-7.67	0.000
	Experimental Group	98	128.19	12563.00	98			
Post Understanding Geometric Properties (Level 2).	Control Group	98	74.37	7288.50	2437.500	7288.500	-6.11	
	Experimental Group	98	122.63	12017.50				
Post Spatial Visualization (Level 3).	Control Group	98	67.44	6609.00	1758.000	6609.000	-7.82	0.000
	Experimental Group	98	129.56	12697.00				
Post Geometric Reasoning (Level 4).	Control Group	98	66.23	6491.00	1640.000	6491.000	-8.34	0.000
	Experimental Group	98	130.77	12815.00				
Post Abstract Geometric Concepts (Level 5).	Control Group	98	58.50	5733.00	882.000	5733.000	-11.1	0.000
	Experimental Group	98	98	138.50	13573.00			
Post Mathematical Geometric skills test	Control Group	98	49.78	4878.50	27.500	4878.500	-12.1	0.000
	Experimental Group	98	98	147.22	14427.50			

To capture complex and nonlinear relationships and provide more in-depth information about the effects of each sensory preference on the post-test performance, the random forest was used to ensure that the analysis is more accurate and comprehensive in answering the second question: Which sense has the most significant impact on geometric thinking performance?

Figure 2 shows that visual (1377) and kinesthetic (1318) sense preferences had the most impact on students' geometric thinking skills. This suggests that students with a preference for visual or kinesthetic senses are more likely to excel. Tactile sense (798) is ranked third. This indicates that they play a supporting but less influential role in influencing performance. On the contrary, auditory (563) sense preference was of relatively low importance. This indicates that these sensory preferences are less important to student success in this context.

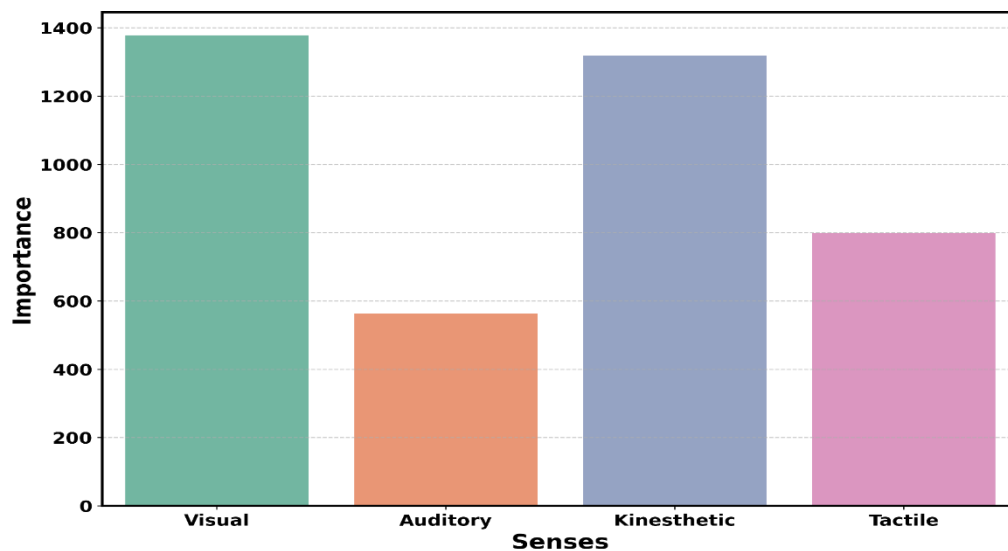


Figure 2. Importance of senses computed using Random Forest.

As well as random forest was used to answer the third question: How do interactions between different senses influence students' performance in geometric thinking?

Figure 3 shows that interaction varies at various levels of combined influence between different preferences and senses on students' performance. The strongest interaction is by kinesthetic and tactile (267), followed by visual and tactile (223), indicating that a combination of tactile and kinesthetic or tactile and visual senses has the strongest effect. Moderate interactions included auditory and kinesthetic (120) and visual and kinesthetic (92), showing that these pairs were useful. Minimal interactions occur with visual and auditory (66) and auditory and tactile (26), suggesting that auditory sense, when paired with other senses, contributes less significantly. These results highlight the importance of combining tactile, visual, and kinesthetic aspects to enhance learning, while auditory pairings have a comparatively weaker combined effect.

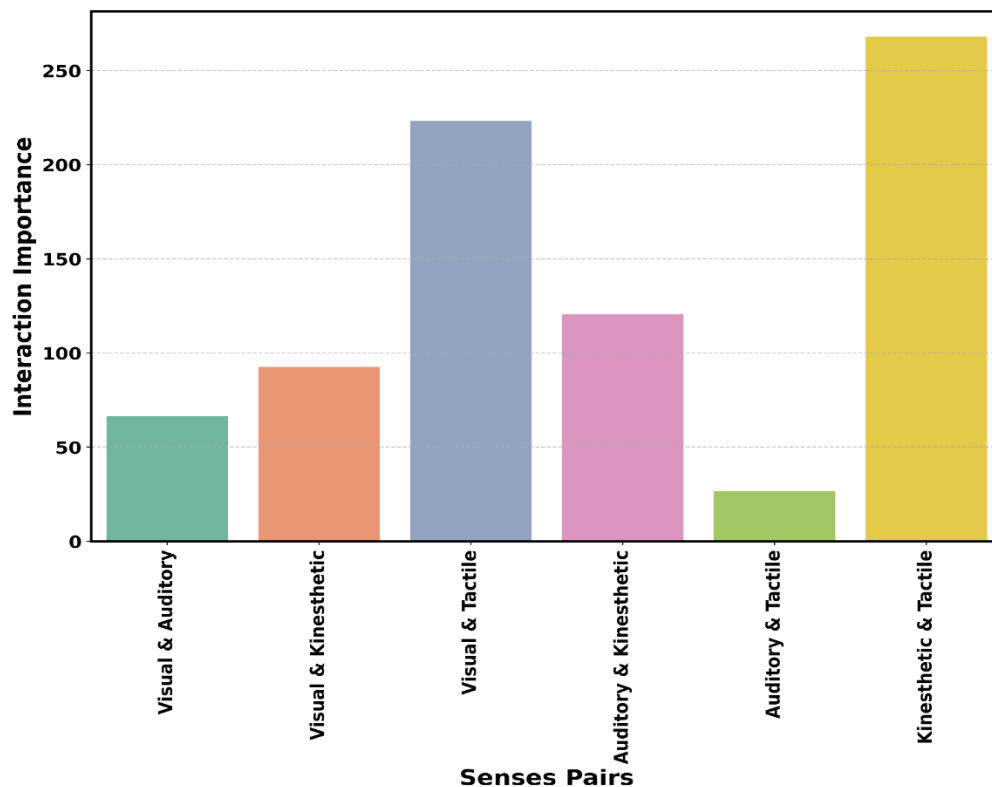


Figure 3. Interactions between different senses using Random Forest.

5. Discussion

This study's results aligned with earlier research indicating that integrating a multisensory approach-based CRA framework into education fosters a learning environment. The findings indicate that this integrated approach improved students' ability to apply geometrical concepts across different contexts. Moreover, the combined application of these preferences effectively reduced performance gaps among students with different sensory preferences (Khan & Khan, 2021).

Additionally, the Random Forest algorithm was employed to offer a comprehensive insight into the relationship between sensory preferences and post-test scores and the relationship between sensory preferences themselves, which may be difficult to access using traditional statistical analyses. The study indicated that students with a visual sensory preference have high performance levels. This discovery corresponds to research that visual sensory can increase cognitive performance; in contrast, a negative relation was noted between auditory sensory preference and geometrical thinking; this may be attributed to the fact that presenting geometric concepts in a verbal manner only does not meet the needs of these students (Augustine et al., 2021; Khatri & Khanal, 2024).

Strong relationships had been shown between kinesthetic and tactile, visual and tactile, establishing it as the most significant factor in achieving success in geometrical thinking. This indicates that students who tend to experiment with manual activities, such as forming geometric shapes and experimenting with geometric tools, achieve better results, while the weakest relationship was between tactile and auditory sensory. These findings suggest that auditory strategies alone may be less effective in supporting geometric understanding among students with learning difficulties (Abah et al., 2023).

6. Conclusion

These findings from the present study have brought into focus the large positive effect size difference of using the multisensory approach based on the CRA framework in teaching geometric concepts among students with learning difficulties. From simple recognition of shapes to abstract ideas in geometry, and from the lowest level to the highest levels of geometric thinking, students who were taught using the multisensory approach based on the CRA framework consistently outperformed their peers who received traditional methods. The study shows the impact of using machine learning (e.g., the random forest algorithm) in uncovering nuanced patterns in the impact of students' sensory preference patterns on their performance, showing how different preferences interact with each other and how they contribute to learning performance. These results underscore the importance of adopting flexible, inclusive, and content-personalized teaching approaches to meet diverse learner needs, and this is consistent with NCTM principles.

7. Suggestion

The key limitation of this study was a controlled environment study with limited external variables; thus, the practical use of a multisensory approach based on the CRA framework in more diverse natural classroom settings may present different results. Moreover, the short intervention period doesn't allow students to check the long-term effects of a multisensory approach based on the CRA framework teaching on geometric thinking and general mathematical skills of students. Further studies need to be conducted with more diverse samples over an extended period to overcome these limitations. Use more advanced machine learning algorithms to uncover deeper relationships and interactions among sensory preferences and levels of geometric thinking skills.

Declarations

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About the Contributor(s)

Duaa Zahi Melhem, Department of Curriculum and Instruction, Faculty of Educational Sciences, Yarmouk University, Jordan

Email: DRDuaaMelhem@gmail.com

ORCID: <https://orcid.org/0009-0001-3936-9441>

Ali Mohammad Al Zoubi, Department of Curriculum and Instruction, Faculty of Educational Sciences, Yarmouk University/ Jordan

Email: ali.m@yu.edu.jo

ORCID: <https://orcid.org/0000-0001-5193-6595>

Mamoon Mohammad Al-Shannaq, Curriculum and Instruction Department, College of Education, Sultan Qaboos University, Sultanate of Oman.

Department of Curriculum and Instruction, Faculty of Educational Sciences, Yarmouk University, Jordan.

Email: m.alshannaq@squ.edu.om, mamoon.shannaq@yu.edu.jo

ORCID: <https://orcid.org/0000-0002-4426-5946>

Amani Saleh Hasan Raiyan, Al-Quds Open University, Palestine.

Email: asrayyan@qou.edu

ORCID: <https://orcid.org/0000-0002-7621-5986>

Hussien Melhem, Teacher at the Ministry of Education, Amman, Jordan

Email: drhusseinmelhem@gmail.com

ORCID: <https://orcid.org/0009-0002-3860-2966>

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