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The Effect of Universal Design for Learning (UDL)-Based VARK Model in Students with Learning Difficulties and Various Learning Preferences

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Abstract

Background/purpose. This study examines whether Universal Design for Learning (UDL), based on the VARK model, can aid struggling students in mathematics in developing their statistical thinking skills. Additionally, the proposed study examines the relationship between learning preferences and the effect of these preferences on performance.

Materials/methods. A total of 196 students were randomly divided into an experimental group and a control group. They completed the VARK questionnaire along with a statistical thinking assessment. The "Statistics and Probability" unit was restructured based on the questionnaire findings and Universal Design for Learning (UDL) principles. Additionally, correlation analysis combined with random forest algorithms revealed links between learning preferences and student performance.

Results. The results demonstrate that the UDL-based VARK model is effective, as there were statistically significant differences in the experimental group's performance at a significance level of $\alpha = 0.05$. Moreover, the findings highlight the predictive power of learning preferences, indicating that visual learning is closely associated with better performance, and it reveals the subtle interactions between learning preferences.

Conclusion. VARK model illustrates that Universal Design for Learning (UDL) effectively enhances statistical thinking skills and emphasizes the relationship between students' learning preferences and their performance. The study reveals notable improvements in statistical thinking skills using the UDL-based VARK model, indicating its potential for a wider application in educating students with learning difficulties.

1. Introduction

The National Council of Teachers of Mathematics (NCTM) stretches mathematical content and provides standards in areas like algebra, geometry, and statistics, establishing standards for what K-12 students should achieve. For students between the ages of 9 and 11, NCTM recommends standards which include questioning procedures for collecting data, organizing data, and presenting it in tables or graphs. They emphasize accuracy and ingenuity in selecting statistical methods for data analysis, including measures of central tendency (e.g., arithmetic mean and median). Standards also encompass reporting predictions and assumptions about data (NCTM, 2000; Adu & Gosa, 2014). Many studies, including Moore (1998) and Dahlstrom-Hakki and Wallace (2022), highlight the importance of teaching statistics. It's essential in various life situations and crucial today, as scientists must consume and produce data simultaneously. Statistics is also regarded as a liberal art and a form of mathematical thinking.

Wild and Pfannkuch (1999) outlined key aspects of statistical thinking: defining data needs, using transnumeration to spot patterns, understanding variation for interpretation, inferring through models, and linking context with results. They also introduced the PPDAC model (Problem, Plan, Data, Analysis, Conclusion) to tackle statistical challenges. This model consists of five phases: defining issues, strategizing data collection, gathering data, evaluating evidence, and interpreting results. Students encounter various challenges in learning mathematics and statistics, which affect their daily lives (e.g., counting money, mental calculations, and interpreting graphs). These difficulties hinder understanding of mathematical concepts and solving tasks, limit arithmetic skills, and create linguistic challenges in interpreting expressions. Visual, spatial, and motor skills are also impacted, complicating the analysis of geometric shapes and graphs (Rajkumar & Hema, 2017). Students struggle with the arithmetic mean and data retrieval from graphical displays in statistics (Julius et al., 2018). Instructional methods aggravate these struggles by focusing on abstract concepts without practical illustrations, leading to memorization instead of understanding (Garfield & Ben-Zvi, 2008).

Different strategies cater to learning problems, specifically the Universal Design for Learning (UDL) strategy. The UDL, based on architectural principles, provides access to diverse needs and fosters diverse modes of learning. It recognizes diverse learning styles, envisioning an elastic system of education with flexible curricula and settings supporting all students irrespective of achievement level (Meyer et al., 2014). Hall et al. (2012) also describe UDL as an education framework based on the science of the brain that accommodates variability in three neural pathways: perceptual (reception of information), strategic (organization and representation of knowledge), and affective (motivational and emotional). UDL is based on three principles: representation (presenting cognitive content in more than one form like sound, pictures, or movies), action and expression (allowing students to represent knowledge in their own way, for example, writing or speaking), and engagement (encouraging student involvement in class work and learning through play) (Rose & Meyer, 2002). Special needs students receive unequal treatment and are isolated from other students, seeing them only during recess. In the majority of classroom environments, they may be present but not engaged. In response to this, policymakers suggest Universal Design for Learning (UDL) to provide equity for all levels of performance (Rao et al., 2017). The Center for Applied Special Technology (CAST, 2018) identifies four elements of UDL curriculum: objectives, declaring anticipated outcomes; diverse learning methods that are appropriate for different needs; instructional strategies outlining teacher actions to accomplish objectives; and assessment, gathering learner performance data to inform educational decisions.

Despite its importance, UDL has shortcomings, such as user misunderstandings. Many think it only serves students with disabilities, but it applies to all learners across achievement levels. UDL is a general guideline meant for all content areas, making it challenging for teachers, especially in abstract subjects like mathematics. It also lacks a flexible, clear design, limiting its implementation (Lambert

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et al., 2021). The VARK model is an educational framework for classifying learning preferences. Developed in 1987 by Fleming, it helps customize content to meet individual needs. It consists of four preferences: Visual (graphs, diagrams), Auditory (podcasts, conversations), Reading/Writing (reading, writing), and kinesthetic (hands-on activities). This model enables educators to tailor teaching methods, fostering an engaging learning environment (Noor, 2023; Pashler et al., 2008).

In Jordan, students with learning difficulties encounter numerous challenges. A primary concern is the insufficient consideration of their learning preferences, which results in low performance in mathematics. These students frequently struggle to connect with conventional teaching methods that fail to address their unique needs. Therefore, innovative strategies are increasingly being adopted to address the needs of these students. Creating a comprehensive and adaptable learning environment encourages their engagement and enhances educational effectiveness. Furthermore, educational content should be tailored to fit the learning preferences of each individual student. This study seeks to address a gap in the existing literature that inadequately focuses on adapting educational content to the diverse learning preferences of students, as outlined by the VARK model within the framework of Universal Design for Learning (UDL). The research will analyze the relationships among various learning preferences, investigate how these preferences interact and support one another, and highlight those preferences that significantly affect student performance. Ultimately, the goal is to foster a learning environment that accommodates a wide range of needs and enhances student efficiency. Therefore, this study aims to answer the following questions:

- What is the effect of using UDL based on the VARK model in improving the statistical thinking skills of fifth-grade students with learning difficulties in mathematics in Jordan?
- What is the relationship between students' learning preferences?
- What is the relationship between students' learning preferences and their performance in statistical thinking?

2. Literature Review

Research on UDL has a long tradition. Marino (2009) conducted an experimental study in the United States to determine the effectiveness of using the UDL strategy in improving the reading skills of students with reading difficulties in science. The study sample consisted of 1153 students in grades 6-8, and the strategy was applied for 4 weeks by 16 teachers. Tests, solution models, and a measure of reading comprehension were applied. The results revealed positive effects of the teaching method in improving their reading skills. By the same token, Marino et al. (2014) conducted a quasi-experimental study in Cascadia to determine the effectiveness of using the UDL strategy in science. The study sample consisted of 57 students in grades 5 - 7 from 4 different schools and from different achievement levels. The strategy was applied by 150 teachers, who were divided between special education and science teachers. The study used a pre-test and a post-test to reveal the positive effects of the strategy.

This has also been explored in prior studies by Mauro (2018), who conducted a study in New Jersey. The study aimed to explore the effectiveness of using the UDL strategy in improving both achievement and mathematical engagement and students' beliefs about the strategy's effectiveness in learning rational numbers. It used a UDL approach for four weeks, using a set of puzzles and mathematical games, colored paper for review, daily tests, and a questionnaire that measured students' opinions and beliefs about the UDL strategy. The sample included seven special needs students in grade 7 from 17 middle schools. In this respect, the findings indicated positive results for UDL in improving achievement and mathematical engagement, a preferred strategy by students.

Kaczorowski et al. (2019) explored the effectiveness of the UDL strategy in improving conceptual learning and increasing the engagement of students with learning difficulties in Europe. The sample

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consisted of 19 students in grade 4. Students were instructed on mathematical ideas of multiplication and division using technology along with the UDL strategy for 10 consecutive weeks. Observation was used, and interviews were conducted with students at the end of the study to find out their opinions about integrating technology. The results revealed the presence of positive effects attributed to the teaching method in understanding mathematical concepts, improving student engagement within the classroom, and students' opinions varied towards the preference of media.

Many authors in the literature have discussed UDL within Arabian contexts as well. Al-Awamreh (2019) conducted a quasi-experimental study in Saudi Arabia to underscore the effect of using the UDL strategy and integrating it with e-learning to teach students with learning difficulties in the engineering unit. A random sample of 54 students was chosen from the fifth grade. They were distributed between a control group and an experimental group. Pre- and post-tests were carried out to measure engineering thinking. The results indicate positive effects for the strategy and prove the effectiveness and integration of the UDL strategy and technology.

Recent work by Root et al. (2020) tried to establish the influence of using the UDL strategy to address the weak points that the students had in solving addition and subtraction from two numbers and verbal problems in the rational number unit. The study sample consisted of students aged 12-15 years old. A special intervention program was designed for each student individually for 3 days a week for 25 minutes in a private room. The cognitive content was supported by a calculator, electronic worksheets, as well as an educational video. The results indicated a positive effect on the direction of the teaching method regarding students' shortcomings.

Yavuzarslan and Arslan (2020) conducted a study in Turkey on how the use of the UDL strategy improves mathematical achievement and students' beliefs towards mathematics and strategy. The study used a mixed approach and included a sample of 33 students in grade 4 who were distributed into two groups: the control group, which included 16 students, and the experimental group, which included 17 students. A test and a tool were designed to measure students' beliefs, and an interview was to reveal students' opinions towards strategy. The results showed positive effects, attributed to the teaching method in improving students' achievement, self-organization skills, and information retention; developing students' beliefs towards learning mathematics and strategy; and enhancing students' engagement in learning mathematics. The study recommended the necessity of integrating it into education.

In the same fashion, Epifanio et al. (2024) conducted a quasi-experimental study to examine the impact of implementing UDL in the statistics curriculum in Spain in the academic year 2022–2023. The sample was 169 students in 2022 and 166 students in 2023. The results revealed that course completion rates and student outcomes improved. In addition, the questionnaire emphasized the effectiveness of UDL in increasing student performance and satisfaction in mathematics and statistics.

Regarding studies related to the VARK Model, Jannah and Bharat (2020) conducted a qualitative study in Indonesia aimed at investigating the learning difficulties of Grade 11 students and identifying their learning preferences. The sample consisted of 40 students. Using questionnaires, tests, and interviews. These problems fall into four main categories: spatial confusion, difficulty understanding concepts, difficulty understanding symbols or equations, and difficulty in calculations. The results indicate that students with a visual learning preference had spatial confusion and difficulty understanding symbols. Meanwhile, auditory learners face challenges with spatial confusion and understanding of concepts and calculations.

On the local level, Bawalsah and Haddad (2020) conducted an experimental study in Jordan targeting 10th-grade students with learning disabilities in public schools providing special education services. The objective of the study was to identify the learning preferences of these students. A total

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of 184 randomly selected students from 10 schools answered a questionnaire to determine their learning preferences and were interviewed to diagnose learning disabilities. The results showed that kinesthetic and auditory modalities were most preferred among students.

Luangrungruang and Kokaew (2022) conducted an experimental study in Thailand with the objective of identifying the learning preferences of deaf students in grades 7-9 based on their learning preferences and universal design principles. Questionnaires and tests are used to assess students' learning preferences and reading comprehension levels. Studies show that strategy improves student outcomes by tailoring content to their specific learning needs. The results showed the effectiveness of a personalized and accessible learning environment.

3. Methodology

The methodology can be outlined in five key steps: data collection, data preparation, Mann-Whitney U test, Correlation Analysis, and Random Forest Analysis. Figure 1 illustrates the structured approach employed in this study, which includes these five main steps for systematically analyzing the data.

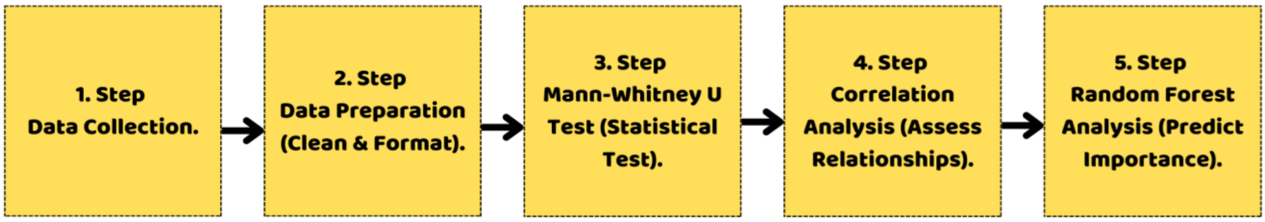

Figure 1. The methodological approach.

3.1. Data Collection

This study utilizes a quasi-experimental design to achieve its objectives. Data is collected from a group of 196 fifth-grade students who have officially been diagnosed with mathematical learning disabilities by a specialist in a resource room at private schools in Irbid. The findings indicate that these students typically belong to middle-class families without major family problems and benefit from both material and emotional support to ensure fair educational opportunities. The sample selection is based on recent diagnostic assessments that verify their specific difficulties.

The study involves two groups: the experimental group, which receives instruction through the new strategy for eight weeks, and the control group, which is taught using conventional methods. Quantitative data is collected using a VARK model questionnaire adapted to determine the students' learning preferences, and a statistical thinking test to measure their capacity to organize, represent, analyze, and interpret data, and reading comprehension.

3.2. Data Preparation (Clean & Format)

To achieve the study goals, the researcher designed the educational material based on an analysis of the statistics lessons in the tenth unit (Statistics and Probability) for the fifth grade. This lesson was scheduled for the second semester of the 2022-2023 academic year. The expected outcomes from the unit were analyzed, and key statistical terms and concepts were identified, including the arithmetic mean, median, range, and mode.

Referring to the study of Murphy et al., (2004) and the website (VARK model), a questionnaire was redesigned to measure students' preferences and desires towards educational content representation, engagement, and expression methods. 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 and teaching methods and learning difficulties. They expressed their opinions

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on the suitability of the phrase to 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 questionnaire in its final form consisted of nine multiple-choice questions with three answer options that correspond to the four learning preferences.

After that, according to VARK responses and based on the recommendations of Root et al. (2020) and Al-Awamreh (2019), the lessons were redesigned according to the three principles of UDL: representation, engagement, and action expression, as defined by CAST (2018). After completing the designing, the educational material was reviewed by specialists in special education and tested on an exploratory sample. Table 1 shows the method of planning lessons based on the UDL guideline and VARK model. In the representation stage, the learner's needs are considered when presenting the cognitive content in several ways and based on the student's preferences. In the second stage, the engagement stage, students choose their preferred method for participating, like play or searching the Internet. In the final stage, action and expression, students present their ideas through special projects like PowerPoint presentations.

Table 1. Steps for designing a lesson according to universal design for learning based on the VARK model

UDL principle	VARK category	Example of activity
Representation Using different representation methods based on students' learning preferences, according to the VARK model.	Visual	• Using concept maps or multimedia presentations.
	Auditory	• Using podcasts.
	Reading/Writing	• Provide students with written stories. • Allow students to write statistical stories.
	Kinesthetic	• Acting data gathering.
Engagement Using different engagement methods based on students' learning preferences, according to the VARK model.	Visual	• Using interactive data visualizations.
	Auditory	• Grouping debates.
	Reading/Writing	• Reading a statistical story and writing a report. • Engaging in reading groups.
	Kinesthetic	• Gathering data from daily life.
Action & Expression Using different expression methods based on students' learning preferences, according to the VARK model.	Visual	• Creating concept maps.
	Auditory	• Creating a statistical podcast.
	Reading/Writing	• Writing journals about statistical concepts.
	Kinesthetic	• Using a theatrical presentation, or different worksheets and tangible materials.

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3.2.1. Statistical Thinking Test

Expanding on Jaradat (2013), a multiple-choice statistical thinking test was created to assess skills in data organization, representation, analysis, interpretation, interpretation, and reading comprehension. The test's validity was established by presenting its initial version and the specific skills it measured to a panel of ten experts in special education, mathematics curricula, and teaching methodologies. Their feedback focused on how well each item aligned with the corresponding skill, the integrity of the language, and the clarity of the phrasing. The panel concluded that the components of the assessment were appropriate and adequate for fulfilling the study's goals. Consequently, the finalized test comprised 30 items, categorized according to the four identified skills.

Using the SPSS program, the responses of a group of 50 participants outside the study sample were analyzed to calculate the difficulty and discrimination coefficients for the test items. The difficulty coefficients were 0.30 - 0.80, while the discrimination coefficients were 0.64 - 0.89. These values fall within the acceptable range for difficulty and discrimination parameters (Crocker & Algina, 1987).

To ensure the reliability of the test, the reliability coefficient was calculated using the internal consistency method according to the Kuder-Richardson-20 (KR-20) equation. Its value reached 0.82, which is a value that indicates that the test has a high degree of reliability and internal consistency (Kuder & Richardson, 1937).

3.3. Mann-Whitney U Test

In order to determine the effect of the UDL approach using the VARK model on statistical thinking skills among the students, the Mann-Whitney U test was employed to analyze post-test results for the experimental and control groups. The test helped in ascertaining whether there was a significant difference in performance between the two groups.

3.4. Correlation Analysis (Assess Relationships)

To investigate the connections between post-test performance and learning preferences (kinesthetic, auditory, reading/writing, visual), Kegel environment, Python, and its libraries—including the Pandas library—were employed. This involved analyzing two sets of correlation matrices:

Relationships among learning preferences: A matrix was developed to evaluate the strength and direction of relationships among the different learning preferences and their interrelations.

Correlation between learning preferences and post-test performance: The second matrix examined how each learning preference was correlated with post-test performance.

3.5. 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 learning preferences in predicting students' post-test performance. This machine learning method evaluates feature importance by generating numerous decision trees while assessing the weight and inaccuracy of the nodes. The random forest model relies on the following equation:

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

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4. Results

The Mann-Whitney test was employed to explore the initial question: How does the application of Universal Design for Learning (UDL) informed by the VARK model enhance the statistical thinking abilities of fifth-grade students facing learning difficulties in mathematics in Jordan?

Table 2 illustrates the strategy's effectiveness, revealing statistically significant differences (α = 0.05) across all dimensions and total scores, favoring the experimental group taught using this strategy:

- **Data Organization:** The study results indicated a significant performance improvement in the experimental group utilizing the strategy, achieving an average score of (126.84) compared to the control group's traditional method score of (70.16), a difference of (56.68). The Z value was-7.137, and the significance level was .000, confirming significant differences favoring the experimental group.

- **Data Representation:** In terms of data representation, the study results showed a significant improvement for the experimental group, which had an arithmetic mean of (123.71) versus the control group's (73.29), resulting in a difference of (50.42). The Z value obtained was-6.311, and the significance level was .000, indicating significant differences favoring the experimental group.

- **Data Analysis and Interpretation:** The findings in data analysis and interpretation demonstrated a clear advantage for the experimental group, which scored an arithmetic mean of (131.09) compared to the control group's (65.91), a difference of (65.18). The Z value was -8.386, and the significance level was .000, indicating significant differences favoring the experimental group.

- **Data Reading and Interpretation:** The data reading and interpretation results revealed that the experimental group's arithmetic mean was (130.12), while the control group's was (66.88), reflecting a difference of (63.24). The Z value was-7.953, with a significance level of 0.000, suggesting significant differences favoring the experimental group.

- **Overall Statistical Thinking Test:** The results indicated that the experimental group had a higher mean rank of (145.30) compared to the control group's mean rank of (51.70), resulting in a difference of (50.42). The Z value is-11.585, and the significance level was .000, confirming statistically significant differences favoring the experimental group.

Table 2. Results of the Mann-Whitney U Test for significant differences in mean ranks

Dimension	Group	N	Mean Ranks	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z Value	Significance Level
Post Data Organization	Control Group	98	70.16	6876.00	2025.000	6876.000	-7.1	.000
	Experimental Group	98	126.84	12430.00				
Post Data Representation	Control Group	98	73.29	7182.50	2331.500	7182.500	-6.3	.000
	Experimental Group	98	123.71	12123.50				
Post Data Analysis and Interpretation	Control Group	98	65.91	6459.00	1608.000	6459.000	-8.4	.000
	Experimental Group	98	131.09	12847.00				
Post Data Reading and Interpretation	Control Group	98	66.88	6554.00	1703.000	6554.000	-7.95	.000
	Experimental Group	98	130.12	12752.00				
Post Statistical Thinking Test	Control Group	98	51.70	5067.00	216.000	5067.000	-11.6	.000
	Experimental Group	98	145.30	14239.00				

4.1. Correlation matrix between the four learning preferences:

The correlation matrix was created using the Kaggle environment, employing Python and its libraries, such as Pandas, NumPy, and Seaborn, to address the second question: What is the relationship between students' learning preferences?

Figure 2 shows connections among four learning preferences. A diagonal value of 1.000000 indicates perfect autocorrelation. The diagonal excess values reflect relationship strength and direction; for example, a moderate negative correlation of -0.35 exists between visual and auditory preferences, suggesting that visual learners often reject auditory methods. Conversely, a strong positive correlation of 0.95 implies that visual learners likely support kinesthetic preferences. Auditory and reading/writing preferences have a moderate positive correlation of 0.46, meaning audio learners also engage in reading and writing. In contrast, a moderate negative correlation of -0.37 exists between auditory and kinesthetic learning, indicating that auditory learners tend to dislike kinesthetic methods. Lastly, a slight negative correlation of -0.23 exists between reading/writing and kinesthetic preferences, showing that individuals tend to favor one learning style over another.

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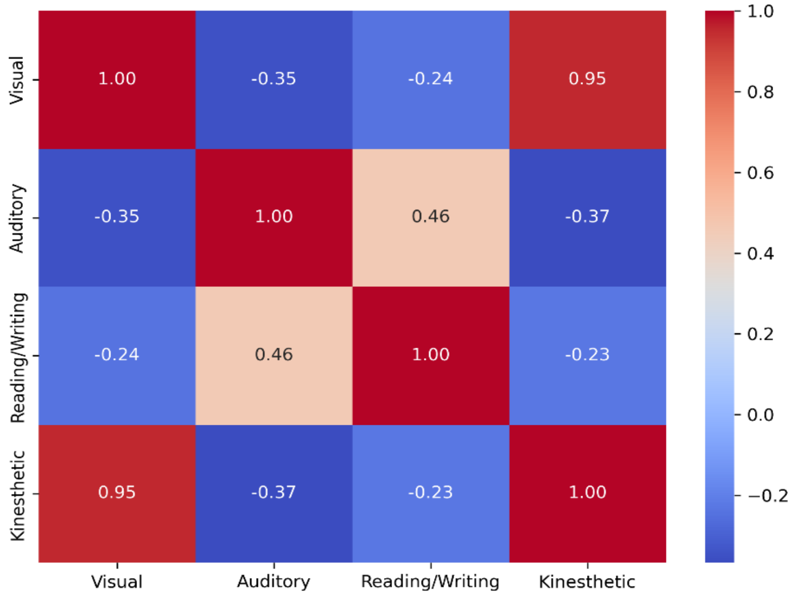

Figure 2. Correlation matrix between the four learning preferences

4.2. Correlation matrix between learning preferences and post-test

The correlation matrix between learning preferences and post-test results addresses the third question: What is the relationship between students' learning preferences and their performance in statistical thinking? Figure 3 shows how the four learning preferences relate to post-test performance. Visual preference has a moderate positive correlation (0.78), suggesting that visual learners perform better. In contrast, auditory preference has a moderate negative correlation (-0.68), indicating that auditory learners perform worse. Reading/Writing shows a slight negative correlation (-0.55), indicating an inverse relationship. Kinesthetic preference has a strong positive correlation (0.78), indicating kinesthetic learners tend to score higher.

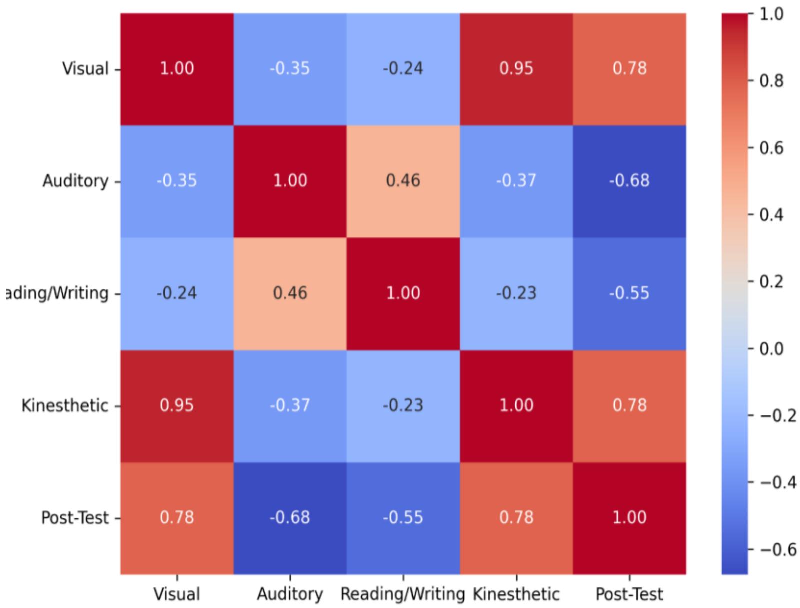

Figure 3. Correlation matrix between learning preferences and post-test results

4.3. Utilization of Random Forest

We used a random forest for greater analysis accuracy to capture complex relationships and provide in-depth information about learning preferences on post-test performance. Figure 4 shows the importance of features from the random forest, based on the weight and impurity of nodes in each tree. The visual learning preference scores 0.41, having the highest impact among the four preferences. The auditory preference follows with a score of 0.26. Reading/writing patterns have a low importance value of 0.092, indicating they play a minor role in predictions. Kinesthetic preference scores 0.23, demonstrating its significant effects, though lower than auditory. These results show how the random forest assessed the relevance of each preference for predicting post-test performance.

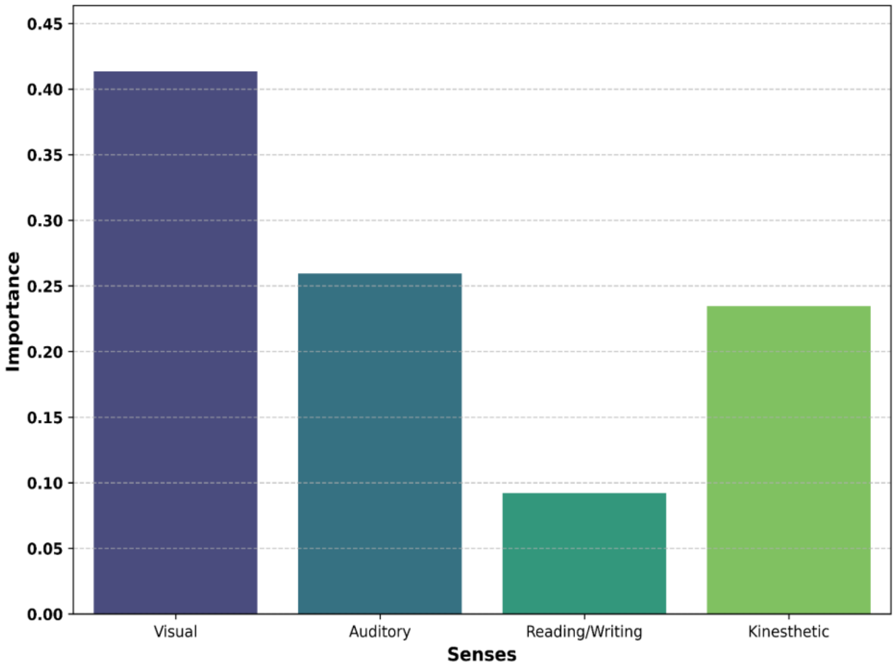

Figure 4. The importance of features computed using Random Forest.

5. Discussion

This study's results align with earlier research, indicating that integrating Universal Design for Learning (UDL) based on the VARK model into education fosters a more inclusive and adaptable learning environment. The findings indicate that this integrated approach improved students' ability to apply statistical concepts across different contexts. Moreover, the combined application of these preferences effectively reduced performance gaps among students with different learning preferences (Luangrungruang & Kokaew, 2022).

Conversely, correlation analysis uncovered a moderate negative connection between visual and auditory learning preferences. This suggests that students who prefer one learning preference typically do not favor the other. Additionally, a strong positive correlation was found between visual learning and post-test performance, highlighting the significance of visual learning techniques in enhancing students' statistical thinking skills. This aligns with previous studies (Augustine et al., 2021; Khatri & Khanal, 2024). In contrast, a moderate negative correlation was noted between auditory learning and post-test performance, implying that auditory learners might struggle with statistical thinking. This suggests refining auditory learning methods, such as incorporating interactive discussions and podcasts. Similarly, the random forest algorithm offers a comprehensive insight into the relationship between learning preferences and post-test performance. Analysis of feature importance scores from the random forest model reaffirms the strong predictive capability of visual learning, establishing it as the most significant factor in achieving success in statistical thinking. This finding is consistent with the correlation analysis, further emphasizing the crucial role of visual learning strategies in fostering statistical comprehension. Moreover, random forest algorithms can uncover patterns that remain hidden in correlation analyses, such as the joint effects of auditory preference (Schulze & Bosman, 2018).

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6. Conclusion

This quasi-experimental research investigates whether UDL based on the VARK model can effectively enhance the mathematical abilities of students with learning difficulties, particularly in statistical thinking. A total of 196 students were randomly divided into an experimental group and a control group, and the "Statistics and Probability" unit was restructured based on the findings of the questionnaire and the principles of Universal Design for Learning (UDL). Correlation analysis, along with random forest algorithms, revealed links between learning preferences and student performance. The findings showcase the strategy's superiority over conventional methods, revealing statistically significant enhancements in statistical thinking and four associated skills. They illustrate the role of machine learning, including the random forest algorithm, in identifying subtle patterns that influence learning performance based on varying preferences. These outcomes underscore the importance of implementing flexible, inclusive, and personalized teaching methods to meet the varied needs of students, consistent with UDL principles.

7. Suggestion

The results show that visual learning preferences are more effective, which means they are used more by students with learning difficulties. As this study did not examine the interaction of multiple learning preferences, future work should examine these interactions utilizing machine learning algorithms, for instance, the gradient boosting algorithm. Future studies could also consider different mathematical topics and diverse populations to yield more generalizable findings. Utilizing more advanced machine learning algorithms could reveal deeper connections and interactions between learning preferences and student performance.

Declarations

Author Contributions. All authors contributed equally to the study and approved the final version of this article.

Conflicts of Interest. The authors declare no conflict of interest.

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Data Availability Statement. The data can be provided by the corresponding author upon request.

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