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LATIN SQUARE DESIGN: A METHODOLOGICAL INNOVATION IN EDUCATIONAL RESEARCH FOR IMPROVED TEACHING AND LEARNING

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ABSTRACT

A Latin square design (LSD) is a specific arrangement of integers, letters, or symbols, where each element appears exactly once in each row and column. Latin squares have long fascinated mathematicians, with a rich history and various applications in mathematics and other fields. It is more efficient and hence more powerful than reasonable alternatives such as Completely Randomized Design (CRD) or Randomized Complete Block Design (RCBD). Educational researchers also realized that Latin squares could be used in their work, but Latin-square designs do not appear to have been adopted in education anywhere near as often as in medical research. The review of how educational researchers have made use of Latin-square designs in their experiments. This work focuses on the performance of students of six classes in six different subjects by six different teachers using six different methods of teaching. A 6 × 6 Latin square design was employed. The descriptive statistics tables shows that SS3 students perform better with minimum average of failure (21.33%), all classes perform better in Ahmadu's subjects that is Biology and Basic Science with minimum average failure (22.67%) and Method C (i.e. Deductive method) yield better result with minimum average failure (22.17%). From the Analysis of Variance, the p-value obtained for the three variables; Classes, Teachers and Methods of teaching given as 0.556, 0.612 and 0.842 respectively indicates that the null hypotheses are accepted and conclude that the differences between classes, teachers and method of teachings are not significant.

Keywords: Latin Square Design, Educational Research, Experimental Design, Statistical Analysis, Student Learning Outcomes

INTRODUCTION

A Latin square is a square matrix with the same number of rows and columns, where each cell contains a symbol from a sequence, and each symbol appears only once in each row and column. The concept of Latin squares was first proposed by Fisher (1925), as a useful tool in experimental designs to control for extraneous variables. Fisher recommended randomly selecting a Latin square from the set of possible squares that fit a research design and incorporating the Latin-square design into the data analysis (Richardson, 2018). While psychological researchers have recognized the value of Latin-square designs, they have not fully utilized them and have not followed Fisher's recommendations. Educational researchers have used Latin-square designs even less, leaving them vulnerable to similar criticisms. Despite these limitations, the judicious use of Latin-square designs can be a powerful tool for experimental researchers, allowing for more precise control over extraneous variables and more accurate analysis of results.

Latin square design is a specific type of configuration of integers, letters of the alphabet, or different symbols. Latin squares had been of interest to mathematicians for a completely lengthy time. In this situation, we can take the case while we've got nuisance elements that we want to manipulate them with the aid of using blockading them off in an instruction to be able to look at the impact of a remedy variable. The layout for conducting that is referred to as a Latin Square Design. We introduce the outline of this layout and evaluation of variance of the layout. Sir Ronald A. Fisher becomes the primary statistician that implemented a proper experimental mathematical model (Fisher, 1971).

Fisher (1925) proposed that Latin squares could be useful in experimental design. He argued that Latin squares should be chosen at random and used in data analysis. Educational and psychological researchers have used Latin squares only rarely. Those who have used Latin squares have often not heeded Fisher's prescriptions. Nevertheless, the judicious use of Latin-square designs can be a powerful tool.

Fisher was interested in agricultural experiments, but researchers in other fields came to realize that Latin-square designs could be useful in their work. This is notably the case in medical research, where it is nowadays widely recognized that Latin-square designs provide an efficient and effective way of controlling for the effects of extraneous variables, especially the effects of temporal order or sequence in repeated-measures designs. On February 7, 2017, the bibliographic database MEDLINE recorded a total of 4055 publications since 1948 that contained the phrase "Latin square" in their titles, abstracts, keywords, or metadata, yielding an average of 58.8 such publications per year over the relevant 69-year period.

Educational researchers also realized that Latin squares could be used in their work, but Latin-square designs do not appear to have been adopted in education anywhere near as often as in medical research. Informal enquiries suggested that nowadays many educational researchers are unaware of their existence, and that their students do not learn about these designs in the course of their training. This is exceedingly unfortunate, because educational researchers may be missing the opportunity to exploit a potentially valuable tool in the design of their experiments. Accordingly, our aim in this article is to advocate the more widespread use of Latin-square designs in educational research.

LSDs are more efficient and hence more powerful than reasonable alternatives such as Completely Randomized Designs (CRD) or Randomized Complete Block Designs (RCBD). The review of how educational researchers have made use of Latin-square designs in their experiments. In fact, such designs have been more widely adopted in psychological experiments, and so the review of how psychological researchers have made use of Latin-square designs. Comparing research practice in these two disciplines with a focus on whether they have complied with Fisher's stipulations regarding the use of Latin-square designs in experiments. It is concluded by advocating the more formal and rigorous use of Latin-square designs in future educational research.

A Latin square is a grid or matrix containing the same number of rows and columns (say, k). The cell entries consist of a sequence of k symbols (for instance, the integers from 1 to k, or the first k letters of the alphabet) inserted in such a way that each symbol occurs only once in each row and only once in each column of the grid.

Educational researchers seem to have lagged behind their psychological counterparts in their appreciation of Latin squares. Statistical Analysis in Educational Research. However, according to (Feldt, 1979) by the 1950s he felt that this needed to be radically revised and updated to incorporate the advances that had been made in mathematical statistics in the intervening years. The result was an entirely new in educational research, this means each student or group is exposed to each educational intervention or method once, but in a different order or context (e.g., different time, different location).

LSDs are used for the following reasons; Control for Confounding Variables, Reduce Bias and More Efficient than other designs.How to Apply in Education?Imagine you want to test the effectiveness of three different teaching methods (A, B and C) on student performance. You could use a Latin square design to ensure each method is taught to each class in a different order, controlling for potential order effects.Latin square designs can be used in various educational contexts, such as; comparing different instructional materials.Evaluating the effectiveness of different teaching strategies.Studying the impact of different learning environments.

Assuah (2019), in his study compared the effectiveness of four teaching methods; Direct Instruction, Inquiry-Based, Cooperative and Guided Discovery. The study employed a 4 × 4 Latin-Square design, involving; Four Classes, Four Teachers, Four Teaching Methods and Forty Students from a school district in the western region. The results indicated significant main effects for; Teacher: $F(3, 15) = 37.50$, $p < 0.05$, $\eta^2 = 0.95$. Class: $F(3, 15) = 755.83$, $p < 0.05$, $\eta^2 = 0.99$. Teaching Method: $F(3, 15) = 37.50$, $p < 0.05$, $\eta^2 = 0.98$. These findings suggest significant differences in students' scores with respect to teacher, class, and teaching method.

This study explores the application of neutrosophic statistics to the Graeco-Latin Square Design (GLSD), introducing a novel approach for analyzing GLSDs with uncertain observations. The proposed approach involves; Neutrosophic ANOVA andNeutrosophic Hypotheses and Decision Rule. The performance of the proposed design is evaluated through the Numerical Examples and Simulation Study. The results indicated that the GLSD under neutrosophic statistics outperforms the GLSD under classical statistics when dealing with uncertain observations, demonstrating the benefits of using neutrosophic statistics in GLSD analysis (AlAita et al, 2024).

Zhang et al (2022),conducted astudy that employed an 8 × 8 Latin square design to evaluate eight cotton cultivars in two Fusarium oxysporum f. sp. vasinfectum Race 4 (FOV4) infested fields, with two trials conducted in each field. The evaluation was based on two key parameters; Mortality Rate (MR) and Root Vascular Staining (RVS). In their experimental design, the study consisted of Field Trials and Greenhouse Trials. While, two trials of the same design were conducted in a greenhouse for comparison. The analysis of variance revealed that; the Tier Effects: Significant effects due to tiers (not planting rows) were detected in the Texas location only. And, Cultivar Variation: Significant variation due to cultivars was consistently detected in both trials and locations.

Adamu et al (2020), employed Latin Square Design ANOVA to investigate the effects of NPK and Urea fertilizers on tomato growth and yield. To further examine the differences between fertilizer levels, a post-hoc analysis was conducted using the Least Significant Difference (LSD) test. The results indicate that both NPK and Urea fertilizers significantly impact tomato growth and yield across various zones and fertilizer application levels. Moreover, the overall model for tomato yield was found to be robust and reliable.

A Partially Balanced Incomplete Block Design (PBIBD) based on the L2 association scheme has been previously constructed using Mutually Orthogonal Latin Squares (MOLS). This design has specific parameters, including; v=p2, b=pp−1, r=p−1, k=p, λ1=0, λ2=1, n1=2p−1, n2=p−12. This note presents an alternative method for constructing such PBIB designs using circulant matrices. A generalized method for constructing PBIB designs based on the L2 association scheme is also provided, with parameters; v=p2, b=p2s+tp−1, r=2s+tp−1, k=p, λ1=s, λ2=t, n1=2p−1, n2=(p−1)2, where p is a prime number, and s and t are integers(Saurabh & Singh, 2022).

Hartung et al, (2022) carried out a research on the Latin Square Task (LST) proposed as a theoretically grounded paradigm for assessing fluid intelligence. This research investigates the psychometric properties of LSTs through four comprehensive studies involving a total of 3,439 participants. The results of these studies provide evidence for; Undimensionality, Stimulus Types and Rotation, and Validity in the expected range (approximately $r = 0.50$). These findings have significant implications for the use of LSTs in unsupervised automated testing, suggesting that they can be a reliable and valid measure of fluid intelligence in such contexts.

Zeuch et al. (2011), in their study explores the cognitive parameters and structure of LSTs, as defined by Relational Complexity Theory (RC-Theory), using Item Response Theory (IRT)-based Linear Logistic Test Models (LLTM). The study involved; Participants: 850 German school students, Task: Completing 26 systematically designed LST items. The results include, Support Rasch-scalability and LLTM analyses which revealed that both operation complexity and number of operations affect item difficulty

Chen et al (2024), in their study ina new image encryption method is compared to existing state-of-the-art schemes, demonstrating: They proposed method excels in; Usability, Security and Efficiency.

This chapter explores the applications of combinatorics in cryptography, covering: Overview of combinatorics in cryptography, Historical context that Focus on Combinatorial Squares and Cubes. Their discussion sets the stage for further exploration of Latin squares in secure encryption-decryption algorithms (Zolfaghari & Bibak, 2022).

Beall (1971), in his guide introduces various innovative experimental designs for data analysis while reviewing established procedures. By focusing on practical experimental challenges rather than complex mathematical models, it aims to inspire new applications. Key topics include; change-over experiments, youden fields, carry-over effects, designing youden experiments and analyzing data. The guide's approach is problem-oriented, targeting real-world experimental issues to foster broader applicability.

Adedoyin et al (2023), this research develops a comprehensive online E-Learning System, enabling teachers to create, administer, and assess courses seamlessly. The Learning Management System (LMS) offers features like: Learning plan creation, learning process implementation and Assessment/evaluation tools. In their technical Details, the system was built using: JavaScript (Vue) for frontend development, PHP for server-side programming and NoSQL database for efficient data management. The system was tested by potential users and successfully met predefined requirements, ensuring its effectiveness and usability.

This quantitative study investigates the effectiveness of the Latin Square Design (LSD) model in prioritizing cybersecurity threats and linking information assurance defense-in-depth measures to those threats. The study employed a multi-step approach such as; Cybersecurity Website Scanning, Likert Scale Model, LSD Model Application and Hypothesis Testing. The study's results rejected the null hypothesis. The findings have implications for the development of effective cybersecurity strategies and the prioritization of information assurance measures to protect organizational devices against cyber threats (Alexander, 2020).

Sapam et al (2021), extended their previous research on Latin Square Designs (LSDs) of orders 5 and 6. They examine the same linear model in greater detail, focusing on; Estimable Parametric Functions and Error Functions. The analysis builds upon the same linear model used in previous studies, with a specific emphasis on understanding the impact of RN and CN effects on LSDs of orders 5 and 6. This research aims to provide a deeper understanding of LSDs and their applications, particularly in situations where RN and CN effects are present. Their findings can inform the design and analysis of experiments in various fields.

Gao et al (2023), in their article proposes a hybrid algorithm combining Orthogonal Learning Strategy (OLS) with PSO to overcome local optima issues. The OLS-based PSO algorithm; Escapes local optima that is OLS is applied when the PSO algorithm gets stuck, helping the population move to better positions. And, Improves convergence meaning the algorithm achieves

A study involving 277 participants (71.2% response rate) evaluated the effectiveness of text messaging interventions in promoting sun protection habits. The results showed that, it improved sun protection habits and reduced sunburn rates that's it significantly decreases in sunburn rates over time, with reductions sustained during intervention periods. They concluded that regular text messaging interventions effectively promote sun protection habits and reduce sunburn rates in young adults (Horsham et al, 2021).

This researchers refines the traditional Latin Square Design to objectively assess readers' comprehension across multiple texts and iterations. The study explores Latin Square methodology that Adapted for vocabulary testing through multi-pass reading materials. And, Challenges and opportunities that Strategies to enhance validity and reliability. Their aim is to accurately capture readers' performance and improve vocabulary assessment (Peng & Yuan, 2024).

Rankovic et al (2023), conducted a studythat analyzed data from 27,801 participants across two cross-sectional studies (2013-2019) to identify prevalent chronic diseases in Serbia. The study compared; decision Tree and Support Vector Regressor models and ANN-L36 model. Results revealed cardiovascular diseases, Hypertension and Decrease in hypertension from 34.0% in 2013 to 32.2% in 2019.

The second edition of "Latin Squares and their applications" provides a long-awaited update and reissue of this seminal work. The revised edition retains the foundational material from the original 1974 volume, while incorporating new information and updates throughout. The new edition features the following; retains original material, updated throughout and expanded coverage. The author's goal remains to guide readers from the basics of the subject to the frontiers of research, providing a comprehensive understanding of Latin squares and their applications. The book aims to reflect the current state of knowledge in the field (Keedwell & Dénes, 2015).

We developed a cutting-edge system combining randomized block design analytics with Latin square design principles to enhance crime detection and parking management. The Key Features are; Automates parking allocation and Integrates license plate scanning and object recognition. The system could save time and fuel also Enhance crime detection*: Through advanced vehicle identification and tracking (Jahnavi & Anithaashri, 2024)

Hua et al (2021), proposes a new method for constructing S-boxes using a combination of complete Latin squares and chaotic systems. The methods such as, Generating Complete Latin Squares and S-Box Construction was used. The results of the performance analysis show that the S-box generated by this method has High Performance and Resistance to Attacks. The method offers a promising approach for constructing high-performance S-boxes, which are essential components in many cryptographic systems. The results of this study can contribute to the development of more secure cryptographic protocols.

Madhusudanan et al (2018), in their research introduces a new pattern for positioning Photovoltaic (PV) modules using the Latin square pattern, without altering the total cross-tied electrical connection. The proposed pattern offers several advantages such as; Uniform Shade Dispersion and Elimination of Multiple Peaks: The shade dispersion pattern eliminates multiple peaks in the PV curve, enabling the use of simple algorithms to track the Maximum Power Point (MPP). The Latin square pattern is evaluated under various partial shading conditions, and the results demonstrate improved performance under these conditions.

A rank test for Latin square data is introduced, with various forms to accommodate different scenarios; no ties, ties with mid-ranks and ties in general. These adjustments are similar to those used in other non-parametric tests, such as the Kruskal-Wallis, Friedman, and Durbin tests. The ANOVA F test on ranks, also known as the rank transform test, is a competitor test. When data are aligned before ranking, this test is referred to as the FART test. The two Proposed Tests are; Permutation Aligned RL Test (PARL) and Chi-Squared Approximation RLTest (CARL). A simulation study, assuming a parametric model and testing the null hypothesis that the treatment parameter is zero, shows that; CARL, PARL, FART and F Test on Raw Data are all control their type I errors well and have comparable powers (Livingstonet al, 2024)

A Latin square is a matrix with equal rows and columns, containing k symbols and unique symbol occurrence. Each symbol appears once in each row and column.A 4x4 Latin square contains integers 1-4, each occurring once in each row and column. This corrigendum addresses an error in Richardson's (2018) account on Latin squares in research design, providing clarification (Higham & Richardson 2021).

Kumar et al (2024), in their research introduced emerging approaches based on Fuzzy logic, Intuitionistic fuzzy logic and Neutrosophic logic. Neutrosophic Graeco-Latin Square Design. This paper reviews Graeco-Latin Square Design (GLSD) history, proposes neutrosophic Graeco-Latin square design and illustrates with experimental study. The study demonstrates the design's potential in Analyzing complex systems and also improving understanding of burning rate effects.

MATERIALS AND METHODS

Latin Square Designs (LSD) are an arrangement of r letters each repeated r times in a square array of size r in such a manner that each letter appears once in each row and each column. Usually treatments are allotted to rows and columns at random.

Latin Square Designs

Let A, B, C, D, E and F represent 6 treatments. It conventional with LSD to use Latin letters for the treatments. A Lain Square Design is given in the table below.

Table 1: Shows a 6 × 6 Latin-Square design

	COLUMN					
ROW	**1**	**2**	**3**	**4**	**5**	**6**
1	A	B	C	D	E	F
2	B	C	D	E	F	A
3	C	D	E	F	A	B
4	D	E	F	A	B	C
5	E	F	A	B	C	D
6	F	A	B	C	D	E

Table 1: Column 1 would run treatment A in Row 1, Bin Row 2, and so on for the other Column. Note that each Column runs each treatment in each Row. A LSD has the following features; there are r treatments, there are two blocking variables each containing r classes. Each row and each column in the design square contains all treatments; that is, each class of each blocking variable constitutes a replication.

Latin Square Design Model

A Latin Square Design Model involves the main effect of the row blocking variables, denoted by ρ_i, the main effect of the column blocking variable, denoted by κ_j, and the treatment main effect, denoted by τ_k. It is assumed that no interactions exist between these three variables. Thus, the model employed is an additive one. For the case of fixed treatment and block effects, the model is:

$$Y_{ijk} = \mu + \rho_i + \kappa_j + \tau_k + \varepsilon_{ijk} \quad (1)$$

Where, μ is a constant, ρ_i, κ_j, τ_k are constants subject to the restrictions and ε_{ijk} are independent $\sim(0, \sigma^2)$

Partitioning of the Sum of Squares

$$Sum\ of\ Square\ Total\ (SST) = \sum_i \sum_j \sum_k Y_{ijk}^2 - \frac{Y_{...}^2}{N}, \quad (2)$$

$$Sum\ of\ Square\ Row\ (SSR) = \frac{\sum_{i=1}^{n} Y_{i..}^2}{r} - \frac{Y_{...}^2}{N}, \quad (3)$$

$$Sum\ of\ Square\ Colunm\ (SSC) = \frac{\sum_{i=1}^{n} Y_{.j.}^2}{r} - \frac{Y_{...}^2}{N}, \quad (4)$$

$$Sum\ of\ Square\ Treatment\ \ (SStr) = \frac{\sum_{i=1}^{n} Y_{..k}^2}{r} - \frac{Y_{...}^2}{N} \quad (5)$$

Table 2: ANOVA Table

Source of Variation (SV)	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	f-ratio
Row	SSR	$r - 1$	$\frac{SSR}{r-1}$	$\frac{MSR}{MSE}$
Column	SSC	$r - 1$	$\frac{SSC}{r-1}$	$\frac{MSC}{MSE}$
Treatment	SStr	$r - 1$	$\frac{SSTr}{r-1}$	$\frac{MStr}{MSE}$
Error	SSE	$(r - 1)(r - 2)$	$\frac{SSE}{(r-1)(r-2)}$	
Total	SST	$r^2 - 1$		

For the purpose of this research, the dataset were collected from Day Secondary School, Kamfanin Bobi in Niger state. The ability of the teachers in using different methods of teaching in different classes were observed and the performance of the students were tested. The six teachers with their area of specialization and teaching subjects in the school are shown in table 3:

Table 3: Shows the staff with their area of specialization and teaching subjects

S/No	Staff	Area of Specialization	Teaching Subject
1	Mohammed G. Bagobiri	Hausa	Hausa (All Classes)
2	Usman Nuhu	Statistics	Mathematics (All Classes)
3	Markus I. Iko	Electrical/Electronics	Chemistry (SS 1 – 3) Basic Tech (JSS 1 – 3)
4	Ahmadu Abdullahi	Biology	Biology (SS 1 – 3) Basic Science (JSS 1 – 3)
5	Sanusi Abdullahi	Computer Science	Economics (SS 1 – 3) Computer (JSS 1 – 3)
6	Mustapha Sani	Physics	Physics (SS 1 – 3) Business Studies (JSS 1 – 3)

Teaching methods are given as: A = Lecture Method, B =Inductive Method, C = Deductive Method, D = Discovery Method, E = Laboratory Method and F = Analytic Method.

Table 4: The outcome of the experiments

	Mohammed	Usman	Markus	Ahmad	Sanusi	Mustapha
JSS 1	35 A	17 D	16 C	18 E	44 B	17 F
JSS 2	11 B	42 A	14 E	21 C	40 F	39 D
JSS 3	29 C	28 E	45 D	34 F	19 A	49 B
SS 1	23 D	17 C	36 F	24 B	41 E	16 A
SS 2	21 F	45 B	31 A	14 D	31 C	35 E
SS 3	19 E	28 F	13 B	25 A	24 D	19 C

RESULTS AND DISCUSSION

The hypotheses are:

H_{01}: Students' performance are same with respect to class Vs H_{11}: not the same with respect to class

H_{02}:Teachers'ability in teaching per class are same Vs H_{12}: are not the same per class

H_{03}:Teaching methods have no significant difference in yielding results Vs H_{13}: There is significant difference

Table 5: Mean per Classes

Classes	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
JSS1	24.500	4.836	14.413	34.587
JSS2	27.833	4.836	17.747	37.920
JSS3	34.000	4.836	23.913	44.087
SS1	26.167	4.836	16.080	36.253
SS2	29.500	4.836	19.413	39.587
SS3	21.333	4.836	11.247	31.420

Dependent Variable: FAILURE

Table 5, indicates that the mean of SS3 (i.e. 21.3) which is the minimum among the means perform well, because it has minimum average failure. While, JSS3 with highest mean of 34 perform below the expectation.

Table 6: Subject Teacher

Subject Teacher	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Mohammed	23.000	4.836	12.913	33.087
Usman	29.500	4.836	19.413	39.587
Markus	25.833	4.836	15.747	35.920
Ahmadu	22.667	4.836	12.580	32.753
Sanusi	33.167	4.836	23.080	43.253
Mustapha	29.167	4.836	19.080	39.253

Dependent Variable: FAILURE

Table 6: The mean number of failure in Ahmadu's subject is the minimum which indicates that the students perform better in Biology and Basic Science because of minimum average failure. There is a great failure in Economics& Computer due to highest mean failure of the students in Sanusi' subject.

Table 7: Methods of Teaching

Methods of Teaching	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
A	28.000	4.836	17.913	38.087
B	31.000	4.836	20.913	41.087
C	22.167	4.836	12.080	32.253
D	27.000	4.836	16.913	37.087
E	25.833	4.836	15.747	35.920
F	29.333	4.836	19.247	39.420

Dependent Variable: FAILURE

Table 7, shows that the mean of failure for method C(Deductive method) of teaching is more effective with the minimum mean failure of 22.17. Follow by E(Laboratory method) with average failure of 25.83, and B(Inductive method) recorded the highest mean failure of 31.00, indicate a poor performance.

Table 8: Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1358.333a	15	90.556	.645	.804
Intercept	26677.778	1	26677.778	190.156	.000
Class	568.222	5	113.644	.810	.556
Teacher	508.889	5	101.778	.725	.612
Method	281.222	5	56.244	.401	.842
Error	2805.889	20	140.294		
Total	30842.000	36			
Corrected Total	4164.222	35			

a. R Squared = .326 (Adjusted R Squared = -.179)

In table 8: All the three variables are insignificant since the significant values are greater than 0.05.

CONCLUSION

From the ANOVA table since the significant value (p-value) for class greater than 0.05 i.e0.556 > 0.05 we fail to reject the null hypothesis and conclude that; "Student performance are the same with respect to class". The significant value (p-value) for teacher is also greater than 0.05 i.e 0.612 > 0.05 we do not reject the null hypothesis and conclude that; "The ability of the teachers in teaching per class are the same" and the significant value (p-value) for method is greater than 0.05 i.e 0.842> 0.05 we accept the null hypothesis and conclude that; "The teaching methods have no significant difference in yielding results for the performance of the student"

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