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## Utilizing Graeco-Latin Square Design to Improve Teaching and Learning Outcomes in Secondary Education

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### Abstract

This study applies the Graeco-Latin square experimental design, an extension of the classical Latin square design, to evaluate the joint effects of multiple instructional factors on students' academic performance while controlling for nuisance variability. The Graeco-Latin square framework enables the simultaneous investigation of four factors—rows, columns, Latin treatments, and Greek treatments—without confounding, thereby ensuring orthogonality and efficient estimation of main effects within a balanced design structure. The empirical application focuses on six classes of students exposed to six subjects, taught by six different teachers employing six distinct teaching methods across six instructional periods. Academic performance was operationalized using students' failure rates, and the dataset was analyzed using Minitab 17. Descriptive statistics revealed that Senior Secondary 3 (SS3) students exhibited the best performance, with the lowest mean failure rate (21.33%). Subjects taught by Aishatu (Biology and Basic Science) recorded comparatively lower failure rates (22.67%), while Method C (deductive teaching approach) yielded improved outcomes (21.91%). Additionally, the sixth instructional period ( $\zeta$ ) demonstrated the most favorable performance, with a minimum average failure rate of 19.25%. Inferential analysis using analysis of variance (ANOVA) indicated that the p-values associated with the four factors—classes (0.594), teachers (0.646), teaching methods (0.571), and instructional periods (0.604)—exceeded the conventional significance threshold ( $\alpha = 0.05$ ). Consequently, the null hypotheses were not rejected, suggesting that variations across these factors are statistically insignificant. The findings imply that, within the experimental constraints, no single factor exerts a dominant influence on student performance, highlighting the robustness of the instructional system under study.

### Keywords

Graeco-Latin Square Design  
Experimental Design and ANOVA  
Teaching Methods Evaluation  
Student Academic Performance  
Orthogonal Design Analysis

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## Introduction

Graeco-Latin squares are a powerful tool in experimental design, allowing researchers to study the effects of multiple factors while controlling for the influence of two blocking variables. This design combines two Latin squares, ensuring that each treatment combination appears exactly once with each level of the other factor in each row and column. By minimizing the impact of extraneous variables, it provides more precise estimates of treatment effects, with applications in various fields, including agriculture, medicine, and industry, it has become an essential component of statistical analysis (Hoshmand, 2018)

A Graeco-Latin square design is a statistical experimental design that combines two Latin squares with different treatments to study multiple variables while controlling for others. This design allows researchers to investigate up to four factors within a single experiment, with two factors represented in rows and columns, and the other two represented by Latin and Greek letters (Montgomery, 2017)

The versatility and efficiency of Graeco-Latin squares make them particularly valuable in situations where resources are limited or experimental units are scarce. By leveraging Graeco-Latin squares, researchers can optimize experimental conditions, reduce costs, and increase the reliability of their findings. Moreover, it enables researchers to identify interactions between factors, uncover hidden patterns, and make informed decisions. As research continues to evolve, the importance of robust experimental designs like Graeco-Latin squares will only grow.

"Education in Late Antiquity" explores the Graeco-Roman debate on education from 300 to 550 CE. Jan Stenger (2021),

examines the evolving views on teaching, learning, and personal formation through the theories of Christian and pagan writers, revealing critiques of traditional education and efforts to reform it.

Mullaney (2018), in his essay introduces a special issue exploring the history of non-Latin type design, focusing on scripts like Arabic, Chinese, Greek, and Devanagari. It brings together designers and scholars to examine the global history of writing and typography, covering regions such as South Asia, East Asia, and South Africa.

Vitruvius' *De architectura* was a groundbreaking work in the history of education for three key reasons: it addressed the educational needs of technical professionals, explored abstract educational issues from an architect's perspective, and advocated for a broad liberal arts curriculum. This chapter examines how posterity responded to Vitruvius' ideas, surveying his influence on ancient curricula and Renaissance architectural treatises (Harris-McCoy, 2024).

This study explores secondary school students' preferences for Latin instruction in the United States. The goal is to inform curriculum development and teaching methods. Over 9,500 current Latin students participated, revealing that mythology, Latin vocabulary, and English vocabulary are their top interests (Goodman, 2015).

Guttek (2022), in his comprehensive volume explores the key ideas and institutions that have shaped Western educational heritage. It examines the global events that have influenced education in Europe, North America, and beyond. The third edition features new material on the ancient world, European exploration, and colonization, as well

as updated chapters on various countries and notable figures like Carl Jung.

A Latin square is a square matrix where each row and column contains a sequence of symbols, with each symbol appearing exactly once in each row and column. Introduced by Fisher (1925), Latin squares can control extraneous variables in experimental designs. Fisher recommended randomly selecting a Latin square from possible options and applying it consistently throughout the research design (Richardson, J. T. (2018).

Graeco-Latin squares have been extensively studied in the context of experimental design. Early work by Fisher (1935) and Yates (1937) laid the foundation for the development of Latin squares, which were later extended to Graeco-Latin squares. Since then, numerous researchers have explored the theoretical and practical aspects of Graeco-Latin squares.

These researchers (Peng & Yuan, 2024) explores the use of Latin Square methodology in vocabulary testing through repeated story readings. It discusses challenges and opportunities of multi-pass reading materials and proposes strategies to improve the validity and reliability of vocabulary assessments, ensuring accurate measurement of readers' performance.

This volume examines the intersection of Latin and music in historical education and culture. It explores the role of Latin in schools, choir schools, and universities, and the impact of musical humanism on music theory, publications, and compositions, particularly in settings of classical and liturgical texts (Forgács, 2021)

Kumar et al (2024), reviews the history of Graeco-Latin square (GLS) designs and

proposes a neutrosophic GLS design, including its model and analysis. An experimental study on rocket propellant formulations illustrates the design's application, analyzing its effects on burning rate.

Hussain et al (2019), this paper explores parameter estimation for Hyper GLaSS Design under random and mixed effect models. A numerical example with hypothetical data illustrates the design's application. Simulation studies demonstrate that Hyper GLaSS Design outperforms Hyper Graeco Latin Square Design in efficiency. A practical example is provided to showcase the design's utility.

This work recounts the captivating story of Abbot Germanos of St. George of Mangana, a prominent Greek monastery in Latin-ruled Cyprus. It explores the monastery's Byzantine roots and ties to Constantinople, then delves into Germanos' appeals to Pope John XXII (1316-1334) regarding a dispute with his monks. Through Germanos' case, the paper examines the complex dynamics of Latin dominance, papal supremacy, and monastic traditions in the Eastern Mediterranean (Kyriacou & Schabel, 2023).

Studies have shown that Graeco-Latin squares are effective in reducing experimental error and increasing the precision of treatment effect estimates (Box, 2005). They have been applied in various fields, including agriculture (Cochran & Cox, 1957), medicine (Fleiss, 1986), engineering (Montgomery, 2017), and marketing research (Kuehl, 2000).

Zhang et al (2018), investigate the construction of pairs of orthogonal Latin squares that are both strongly symmetrical and weakly pandiagonal. We prove that such pairs exist for orders  $n > 4$ , where  $n \equiv 0, 1, \text{ or } 3 \pmod{4}$ , with a potential exception for  $n = 12$ .

Schwitter, R. (2023), examines the connection between school practices and poetic forms in late antique Gaul. Despite the recognized interplay between teaching and literary production, modern scholars often overlook the impact of schools on literary culture. Analyzing sources from Gaul and beyond, this study argues that many Latin poems from this period, both pagan and Christian, reflect educational practices and can be linked to the school system.

Researchers have also investigated the construction and analysis of Graeco-Latin squares. For example, methods for constructing Graeco-Latin squares have been developed using combinatorial mathematics (Laywine & Mullen, 1998). Additionally, statistical analysis techniques have been proposed for analyzing data from Graeco-Latin square designs, including analysis of variance (ANOVA) and regression analysis (John & Williams, 1995).

AlAita et al (2024), they propose a novel approach to analyzing Graeco-Latin square designs (GLSD) under neutrosophic statistics, accommodating uncertain observations. It introduces neutrosophic ANOVA and hypotheses testing, evaluating performance through numerical examples and simulation. The results show that neutrosophic GLSD outperforms classical GLSD in uncertain environments.

This article primarily examines classical and para-literary texts, including thematic and non-thematic bilingual glossaries and glossaries of classical authors. It also explores key bilingual texts, specifically Latin-Greek and Greek-Latin Christian works (Ammirati & Fressura, 2017)

This work carried out by Gordon & Lawton (2019), explores the evolution of Western educational thought from ancient Greek philosophers like Socrates, Plato, and Aristotle to contemporary debates surrounding contentious issues in education. Spanning over 3,000 years, this book examines the continuous development of educational ideas and ideologies. By focusing on the historical context of ideas, this volume shifts the emphasis from individual "great men" to the broader technological, economic, and political factors that shape educational thought and practice.

The role of classical education in today's media-driven world. It highlights effective teaching methods that connect Graeco-Roman studies to modern issues and leverage digital technologies. The study showcases techniques used in various courses over five years, arguing that classical languages and digital technologies complement each other (Bozia, E. (2021)

Recent studies have focused on the application of Graeco-Latin squares in modern research areas, such as clinical trials (Jones & Kenward, 2014) and quality control (Taguchi, 1987). These studies demonstrate the continued relevance and importance of Graeco-Latin squares in experimental design.

Clinical trials: Graeco-Latin squares have been used to design and analyze clinical trials, allowing researchers to study the effects of multiple treatments while controlling for patient characteristics (Jones & Kenward, 2014).

Graeco-Latin squares have been applied in quality control to optimize manufacturing processes and reduce variability (Taguchi, 1987). Graeco-Latin squares have also been

used to study the effects of different fertilizers and irrigation methods on crop yields (Cochran & Cox, 1957).

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 suggest 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.

Educational discussions of Graeco-Latin squares are often discussed in educational settings, particularly in: Statistics and research methods courses: To teach students about experimental design and data analysis. Mathematics and computer science courses: To illustrate combinatorial designs and algorithms.

Graeco-Latin squares offer several benefits, including: Efficient estimation: They provide efficient estimates of factor effects and interactions. Reduced confounding: They minimize confounding between factor effects, allowing for clearer insights.

This work explores motion through the lens of authorial publishing and reading practices. It examines how Greek philosophical schools and Christian monastic communities, such as

Jerome's at Bethlehem and Rufinus' at the Mount of Olives, shaped the dissemination of ideas through their unique reading and publishing practices (Usacheva, 2023)

Subramani (2013), in his research introduces Orthogonal Sudoku Square Designs, presenting a sequential method for constructing these designs of odd order. It also discusses their analysis, illustrated with numerical examples.

These squares can be applied in education in various ways, such as; teaching experimental design: Using Graeco-Latin squares to illustrate experimental design principles and data analysis techniques. Research projects: Encouraging students to design and conduct experiments using Graeco-Latin squares. Interdisciplinary learning: Applying Graeco-Latin squares in multiple subjects, such as mathematics, statistics, and science. Comparing different instructional materials. Evaluating the effectiveness of different teaching strategies. Studying the impact of different learning environments.

### **Materials and Methods**

Graeco-Latin squares are a powerful tool in experimental design, allowing researchers to study the effects of multiple factors while controlling for the influence of two blocking variables. This design combines two Latin squares, ensuring that each treatment combination appears exactly once with each level of the other factor in each row and column. In this arrangement the treatments are grouped into replicates in six different ways, the effect of different sources are equalized for all treatment, each treatment appears once in each row and column and once in each Greek letter

Table 1: Shows a 6 × 6 Graeco-Latin Squares Design

|     |    | COLUMN |    |    |    |    |  |
|-----|----|--------|----|----|----|----|--|
| ROW | 1  | 2      | 3  | 4  | 5  | 6  |  |
| 1   | Aα | Bβ     | Cγ | Dδ | Eε | Fζ |  |
| 2   | Bβ | Cγ     | Dδ | Eε | Fζ | Aα |  |
| 3   | Cγ | Dδ     | Eε | Fζ | Aα | Bβ |  |
| 4   | Dδ | Eε     | Fζ | Aα | Bβ | Cγ |  |
| 5   | Eε | Fζ     | Aα | Bβ | Cγ | Dδ |  |
| 6   | Fζ | Aα     | Bβ | Cγ | Dδ | Eε |  |

Methods of Teaching: A = Lecture Method, B = Inductive Method, C = Deductive Method, D = Discovery Method, E = Laboratory Method, F = Analytic Method

Teaching periods: α = 1<sup>st</sup> period, β = 2<sup>nd</sup> period, γ = 3<sup>rd</sup> period, δ = 4<sup>th</sup> period, ε = 5<sup>th</sup> period, ζ = 6<sup>th</sup> period

The model for the design is given by:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \theta_k + \varphi_l + \varepsilon_{ijkl} \tag{1}$$

Where;  $Y_{ijkl}$  is the observed response,  $\mu$  is the overall mean,  $\alpha_i$  is the  $i^{\text{th}}$  row effect,  $\beta_j$  is the  $j^{\text{th}}$  column effect,  $\theta_k$  is the  $k^{\text{th}}$  Greek letter effect,  $\varphi_l$  is the  $l^{\text{th}}$  Latin letter effect

Partition of total sum of squares

$$SST = SSR + SSC + SSG + SSL + SSE \tag{2}$$

$$SST = \sum_i^r \sum_j^r \sum_k^r \sum_l^r Y_{ijkl} - \frac{Y_{...}^2}{N}, SSR = \frac{\sum_i^r Y_{i...}^2}{r} - \frac{Y_{...}^2}{N}, SSC = \frac{\sum_j^r Y_{.j.}^2}{r} - \frac{Y_{...}^2}{N}, SSG = \frac{\sum_k^r Y_{...k}^2}{r} - \frac{Y_{...}^2}{N}, SSL = \frac{\sum_l^r Y_{...l}^2}{r} - \frac{Y_{...}^2}{N}$$

$$\text{and } SSE = SST - SSR - SSC - SSG - SSL \tag{3}$$

Table 2: ANOVA Table

| Source of Variation (sv) | Sum of Squares (ss) | Degrees of Freedom (df) | Mean Square (ms)             | F-ratio           |
|--------------------------|---------------------|-------------------------|------------------------------|-------------------|
| Row Block                | SSR                 | $r - 1$                 | $\frac{SSR}{r - 1}$          | $\frac{MSR}{MSE}$ |
| Column Block             | SSC                 | $r - 1$                 | $\frac{SSC}{r - 1}$          | $\frac{MSC}{MSE}$ |
| Treatment (Latin)        | SSL                 | $r - 1$                 | $\frac{SSL}{r - 1}$          | $\frac{MSL}{MSE}$ |
| Treatment (Graeco)       | SSG                 | $r - 1$                 | $\frac{SSG}{r - 1}$          | $\frac{MSG}{MSE}$ |
| Error                    | SSE                 | $(r - 1)(r - 3)$        | $\frac{SSE}{(r - 1)(r - 3)}$ |                   |
| Total                    | SST                 | $r^2 - 1$               |                              |                   |

The data of this research were collected from Day Secondary School, Kamfanin Bobi in Niger state. The capability of the teachers using different methods of teaching in different class were noticed and the performance of the students were assessed.

Table 3: List of the Staff with Their Area of Specialization and Teaching Subjects

| S/No | STAFF                   | AREA OF SPECIALIZATION | TEACHING SUBJECT                                   |
|------|-------------------------|------------------------|--|
| 1    | Mohammed Garba Bagobiri | Hausa                  | Hausa (All Classes)                                |
| 2    | Usman Nuhu              | Statistics             | Mathematics (All Classes)                          |
| 3    | Markus Ibrahim Iko      | Electrical/Electronics | Chemistry (SS 1 - 3)<br>Basic Tech (JSS 1 - 3)     |
| 4    | Aishatu Suleman         | Biology                | Biology (SS 1 - 3)<br>Basic Science (JSS 1 - 3)    |
| 5    | Sanusi Abdullahi        | Computer Science       | Economics (SS 1 - 3)<br>Computer (JSS 1 - 3)       |
| 6    | Mustapha Sani           | Physics                | Physics (SS 1 - 3)<br>Business Studies (JSS 1 - 3) |

Table 3 shows the six teachers with their area of specialization and teaching subjects in the school

Table 4: The Result of the Experiment Shown Below

|      | Mohammed       | Usman          | Markus         | Aishatu        | Sanusi         | Mustapha       |
|------|----------------|----------------|----------------|----------------|----------------|----------------|
| JSS1 | 35A $\delta$   | 17D $\alpha$   | 16C $\epsilon$ | 18E $\beta$    | 44B $\zeta$    | 17F $\gamma$   |
| JSS2 | 11B $\zeta$    | 42A $\gamma$   | 14E $\delta$   | 21C $\epsilon$ | 40F $\beta$    | 39D $\alpha$   |
| JSS3 | 29C $\gamma$   | 28E $\epsilon$ | 45D $\beta$    | 34F $\alpha$   | 19A $\delta$   | 49B $\zeta$    |
| SS1  | 23D $\beta$    | 17C $\zeta$    | 36F $\alpha$   | 24B $\gamma$   | 41E $\epsilon$ | 16A $\delta$   |
| SS2  | 21F $\epsilon$ | 45B $\delta$   | 31A $\gamma$   | 14D $\zeta$    | 31C $\alpha$   | 35E $\beta$    |
| SS3  | 19E $\alpha$   | 28F $\beta$    | 13B $\zeta$    | 25A $\delta$   | 24D $\gamma$   | 19C $\epsilon$ |

## Result and Discussion

The hypotheses are:

$H_{01}$ : Performance of Students are same with respect to class Vs  $H_{11}$ : not the same

$H_{02}$ : Ability of teachers in teaching per class are same Vs  $H_{12}$  ability of teachers in teaching not same

$H_{03}$ : No significant difference in teaching methods Vs  $H_{13}$ : significant difference exists

$H_{04}$  The teaching period has no significant effect to the results Vs  $H_{14}$ : there is significant effect

Table 5: Factor Information

| Factor  | Type  | Levels | Values   |
|---------|-------|--------|--|
| CLASS   | Fixed | 6      | JSS 1, JSS 2, JSS 3, SS 1, SS 2, SS 3              |
| TEACHER | Fixed | 6      | Aishatu, Markus, Mohammed, Mustapha, Sunusi, Usman |
| METHOD  | Fixed | 6      | A, B, C, D, E, F                                   |
| PERIODS | Fixed | 6      | $\alpha, \beta, \gamma, \delta, \epsilon, \zeta$   |

Table 6: Mean Per Classes Fitted

| Term  | Mean  | SE   | Mean |
|-------|-------|------|------|
| CLASS |       |      |      |
| JSS 1 | 24.50 | 5.00 |      |
| JSS 2 | 27.83 | 5.00 |      |
| JSS 3 | 34.00 | 5.00 |      |
| SS 1  | 26.17 | 5.00 |      |
| SS 2  | 29.50 | 5.00 |      |
| SS 3  | 21.33 | 5.00 |      |

Table 6 shows that, the mean of SS 3 which is the minimum indicates that the class perform better, because it has minimum average failure. While, JSS 3 recorded the highest failure with the highest mean value of 34%

Table 7: Mean of Failure in Teacher's Subject

|          |       |      |
|----------|-------|------|
| Aishatu  | 22.67 | 5.00 |
| Markus   | 25.83 | 5.00 |
| Mohammed | 23.00 | 5.00 |
| Mustapha | 29.17 | 5.00 |
| Sunusi   | 33.17 | 5.00 |
| Usman    | 29.50 | 5.00 |

Table 7 indicate that, the mean number of failures in Aishatu's subject is the minimum, it means that the students perform better in Biology and Basic Science. While, Teacher Sanusi with mean of 33.17% have mass failure in Economics & Computer Science.

Table 8: The Mean of Failure for Method

|   |       |      |
|---|-------|------|
| A | 32.23 | 6.68 |
| B | 37.45 | 6.38 |
| C | 21.91 | 5.56 |
| D | 24.10 | 5.42 |
| E | 22.81 | 5.45 |
| F | 24.84 | 5.54 |

In table 8, the mean of failure for method C(Deductive method of teaching) is more effective with the minimum mean failure of 21.91%. The effect of the teaching methods is arranged in following order, that is from the best method as; Deductive method, Laboratory method, Discovery method, Lecture method, Analytic method and Inductive method

Table 9: The Mean of Failure for Periods

|               |       |      |
|---------------|-------|------|
| $\alpha$      | 32.79 | 5.54 |
| $\beta$       | 34.81 | 5.72 |
| $\gamma$      | 26.26 | 5.22 |
| $\delta$      | 21.36 | 6.48 |
| $\varepsilon$ | 28.86 | 5.82 |
| $\zeta$       | 19.25 | 6.30 |

In table 9, the mean of failure for period  $\zeta$  (6<sup>th</sup> period) is more effective with the minimum mean failure of 19.25%. The effect of the teaching periods are arrange in descending order that is from the most effective period of teaching:  $\zeta$ (6<sup>th</sup> period),  $\delta$ (4<sup>th</sup> period),  $\gamma$ (3<sup>rd</sup> period),  $\varepsilon$ (5<sup>th</sup> period),  $\alpha$ (1<sup>st</sup> period) and  $\beta$ (2<sup>nd</sup> period)

Table 10: Analysis of Variance

| Source  | DF | Adj SS | Adj MS | F-Value | P-Value |
|---------|----|--------|--------|---------|---------|
| CLASS   | 5  | 568.2  | 113.6  | 0.76    | 0.594   |
| TEACHER | 5  | 508.9  | 101.8  | 0.68    | 0.646   |
| METHOD  | 5  | 594.6  | 118.9  | 0.79    | 0.571   |
| PERIODS | 5  | 556.0  | 111.2  | 0.74    | 0.604   |
| Error   | 15 | 2249.9 | 150.0  |         |         |
| Total   | 35 | 4164.2 |        |         |         |

Table 10 indicate that all the four variables are not significant since the  $\alpha = 0.05$  is less than all significant values

**Conclusion:** the outcomes in table 10 shows that, the significant value for class is greater than 0.05 i.e.  $0.594 > 0.05$  we fail to reject the null hypothesis and conclude that; "Student performance are the same with respect to class". The "p-value" for teacher is also greater than 0.05 ( $0.646 > 0.05$ ) we do not reject the null hypothesis and conclude that; "The ability of the teachers in teaching per class are the same". In methods, The p-value is also greater than 0.05 i.e.  $0.571 > 0.05$  we accept the null hypothesis and conclude as; "The teaching methods have no significant difference in yielding results for the performance of the student". So also the significant value for teaching period is greater than 0.05 i.e.  $0.604 > 0.05$  we equally fail to reject the null hypothesis and conclude that; "The period of teaching a subject does not affect the students' performance.

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