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Research Article

Comparative Analysis of Undergraduate Student Mathematics Performance Evaluated Using Computer-Based and Paper-Based Tests

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Abstract
This research comparatively evaluated the performance of undergraduate students in mathematics using computer-based test and paper-based test in Ignatius Ajuru University of Education. The design for this study was expost-facto survey research design. The population of the study consisted of 246 final year undergraduate students in the Department of Mathematics/Statistics in Ignatius Ajuru University of Education. The sample size used was 196 final year students obtained by systematic random sampling technique. The instrument for data collection was Student Mathematics Score Sheets (SMSS). SMSS was used to collect the scores of students in MTH 421-Partial Differential Equation (PDE) from 2012/2013 to 2017/2018 for the Paper-Based Test (PBT) and from 2018/2019 to 2021/2022 for the Computer-Based Test (CBT). The instrument was validated by three lecturers in the Department of Mathematics/Statistics. SMSS contained items such as examination year, matriculation number, gender, programme, course code, paper-based test score and computer-based test score. The scores of students obtained from the SMSS were analysed using Cronbach Alpha to obtain a reliability coefficient of 0.85 for SMSS. Four research questions and one hypothesis guided the study. Mean and standard deviation were used to answer the four research questions while independent sample t-test was used to test the hypothesis at 5% level of significance. Findings of the study revealed that the computer-based test is significantly better than the paper-based test in evaluating the performance of students in Mathematics. The study among others, recommended that computer-based test be used in evaluating students mathematics performance during course examination in this digital age.
Keywords: Comparative analysis, mathematics, performance, computer-based test, paper-based test

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Research Article

Introduction

Evaluation or assessment is an integral and essential component of educational pedagogy. Evaluation in education is necessary to determine the extent of achievement of learning objectives. There are several techniques of evaluation in education including the traditional paper-based test and the evolving and innovative computer-based test. A test is an evaluation instrument designed to assess the cognitive development of the testee before, during or after instruction (Zalmon et al., 2021). The evolution of educational assessment methodologies has increasingly focused on the potential differences between traditional paper-based testing and emerging computer-based testing approaches, particularly in quantitative disciplines like mathematics. As technological integration in educational environments continues to advance, understanding the comparative performance implications of different testing modalities becomes crucial for educators, institutions, and assessment designers (Johnson et al., 2022). The Computer-Based Test (CBT) is a modern mode of test administration using computer or any other electronic medium. CBT is used in contrast with the Paper-Based Test (PBT) or Paper-and-Pencil/Pen Test (PPT), referring to the use of paper and pen or pencil as evaluation instrument. Using PBT requires testees or examinees to read questions on hard copies and respond in writing. This mode of examination has been associated with poor student performance, examination malpractices and ineffective invigilation and supervision.

Recent studies have highlighted significant variations in student performance and test experience across different testing platforms. Martinez-Garcia and Liu (2023) suggests that computer-based testing can introduce both cognitive and technological challenges that may impact student performance, especially in mathematics, where problem-solving and computational skills are paramount. These variations can stem from factors such as digital interface design, navigation complexity, computational tools availability, and students' individual technological proficiencies. Moreover, the COVID-19 pandemic has accelerated the transition towards digital assessment methods, making empirical research on test modality comparisons increasingly relevant. Thompson et al. (2022) emphasized the need for comprehensive studies that systematically evaluate student performance across different testing formats, considering multiple variables such as test difficulty, student demographics, and technological familiarity. The transformation of educational assessment methodologies has increasingly centered on understanding the nuanced differences between traditional paper-based testing and emerging computer-based testing approaches, particularly in quantitative disciplines like mathematics. As technological integration in educational environments accelerates, comprehensive investigation of testing modality impacts becomes essential for developing robust, equitable assessment strategies (Chen et al., 2023).

The shift from paper-based to computer-based testing represents a significant paradigm change in educational assessment. Historically, paper-based tests have been the standard method for evaluating student knowledge, providing a familiar and linear approach to assessment. In contrast, computer-based testing introduces multiple layers of complexity, including dynamic interface interactions, immediate computational support, and varied response mechanisms (Martinez-Rodriguez et al., 2022). Technological advancements have not only transformed test administration but have also introduced novel challenges in maintaining test integrity, measuring cognitive performance, and ensuring equivalent assessment conditions across different platforms. Research by Williams

and Patel (2023) suggests that the cognitive load associated with navigating digital interfaces can potentially influence student performance, particularly in mathematics where problem-solving requires precise computational and analytical skills. Emerging literature reveals multifaceted differences between computer-based and paper-based testing methodologies. Key considerations include:
Cognitive processing: Digital platforms may alter students' cognitive processing strategies, potentially affecting problem-solving approaches and response times.
Technological proficiency: Students' varying levels of digital literacy can introduce unintended performance variability.
Interface design: The complexity and intuitiveness of digital test interfaces can significantly impact student engagement and test performance.
Computational tool integration: Computer-based tests offer unique opportunities for integrated computational tools, which may advantage or disadvantage certain student groups.

This research holds profound implications for educational assessment design. By systematically comparing undergraduate student mathematics performance across testing modalities, we can: develop more nuanced understanding of test format influences, identify potential performance disparities, inform evidence-based assessment design strategies and contribute to discussions on technological equity in educational evaluation. The COVID-19 pandemic played great role in dramatically accelerating digital assessment adoption and rendering research on testing modality comparisons critically timely. The COVID-19 pandemic significantly accelerated digital assessment adoption, rendering comparative studies increasingly critical. Chen et al. (2023) emphasized the need for comprehensive research addressing technological equity and assessment validity. Thompson et al. (2022) highlighted the urgent need for comprehensive studies that systematically evaluate student performance across testing formats, considering multidimensional variables including technological familiarity, cognitive load, and individual learning differences. The landscape of educational assessment has undergone significant transformation with the increasing integration of digital technologies in testing environments. Recent empirical research has explored the nuanced differences between computer-based and paper-based mathematics assessments across various dimensions. Mehrens et al. (2022) conducted a comprehensive meta-analysis of 47 studies, revealing subtle but significant variations in student performance across testing modalities. Their findings suggest that while overall performance remains relatively consistent, specific cognitive domains demonstrate mode-specific variations. Zhang and Liu (2023) found that computer-based testing can introduce both advantages and challenges, with performance differences varying across mathematical sub-disciplines. Rodriguez-Garcia et al. (2023) investigated the cognitive load associated with different testing platforms. Their experimental study with 423 undergraduate mathematics students revealed that: computer-based tests potentially reduce computational time, digital interfaces may introduce additional cognitive complexity and student technological proficiency significantly impacts test performance.

Thompson and Chen (2022) examined the interaction between technological mediation and mathematical problem-solving. Key findings included: varied performance across different mathematical domains, significant

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Columbia Journal of Education and Social Sciences

Research Article

impact of student technological self-efficacy and potential bias introduced by digital interface design. Patel and Williams (2023) explored the psychological aspects of testing modalities, identifying the following factors associated with computer-based test: increased test anxiety in computer-based environments, variations in student confidence across testing platforms and differential cognitive load between paper and digital testing formats. Other multiple factors influencing performance variability when CBT is used for evaluation of learning are; student technological familiarity, interface design complexity, computational tool integration, cognitive processing differences, institutional technological infrastructure, limited digital literacy, minimal prior exposure to computer-based assessments, lower technological self-confidence, increased test anxiety in computer-based environments, varied perceptions of test fairness and differential comfort levels across technological interfaces (Rodriguez-Garcia et al., 2023). The findings of Rodriguez-Garcia et al. (2023) reveal a nuanced landscape of performance differences between computer-based and paper-based mathematics assessments with statistically significant variations in student performance across testing platforms contrary to simplistic assumptions of technological equivalence. The findings suggest several crucial considerations for future assessment design: need for adaptive testing methodologies, importance of technological skill development, consideration of individual technological proficiencies and development of standardized digital assessment interfaces (Rodriguez-Garcia et al., 2023). Meanwhile, McClelland and Cuevas (2020) compared the performance of students in mathematics using PBT and CBT formats of testing and found out that students performed better in PBT than CBT. Following the variations in the results of previous researchers, this study aims to provide a rigorous comparative analysis of undergraduate student mathematics performance by examining the potential differences between computer-based and paper-based testing methodologies.

Statement of the Problem

Computer-Based Test (CBT) in the recent time has been gaining popularity over the traditional Paper-Pencil Test (PPT) or the Paper-Based Test (PBT) in academic assessment due to many advantages the CBT has compared to the PBT, such as being interactive, exciting, accurate, secure, credible and smooth. However many students and educational educators have also shown interest in PBT than CBT due to their poor performances, complexities, poor computer skills, poor internet connectivity and power failure. Most Universities in Nigeria including Ignatius Ajuru University of Education integrates information and communication technology (ICT) in their teaching, research and community service to meet up with global university ranking and produce quality graduates. In research, ICT promotes global university visibility by making the publications of the academic staff visible and assessable to the global academic community. ICT is also being integrated into another core mandate of the university which is teaching.

Teaching involves instruction, learning and assessment of learning. In learning assessment or evaluation, ICT has made the computer-based test possible which is a great advancement in learning assessment and a paradigm shift from the traditional paper-based test in teaching. CBT was introduced in tertiary education amidst concerns, fears, resistance and affordability. CBT was found very useful in the university educational system especially during the global Covid-19 pandemic. Haven been previously evaluating student learning with the traditional paper-

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Columbia Journal of Education and Social Sciences

Research Article

based test and following the integration of the computer-based test in the university learning assessment, it is therefore the focus of this study to comparatively analyse the performance of students in mathematics when evaluated with CBT and PBT. Hence, this study shall answer the question; what is the difference between the performance of students evaluated using PBT and CBT?

Aim and Objectives of the Study

The aim of this research is to evaluate the performance of students in mathematics using computer-based and paper-based tests in Ignatius Ajuru University of Education. The objectives of the study are to;

1. Ascertain the performance of students in mathematics.
2. Analyse the performance of students in mathematics evaluated using paper-based tests.
3. Determine the performance of students in mathematics evaluated with the computer-based test.
4. Compare the mathematics performance of students evaluated using PBT and CBT respectively.

Research Questions

1. What is the performance of students in mathematics?
2. What is the performance of students in mathematics evaluated using paper-based test?
3. What is the performance of study in mathematics evaluated with the CBT?
4. What is the difference between the performance of students evaluated using PBT and CBT?

Hypothesis

The following null hypothesis was tested at a 0.05 level of significance to guide the study.

Ho1: There is no significant difference between the mathematics performance of students evaluated using paper-based test and computer-based test respectively.

Methodology

The design for this study was expost-facto survey research design. The population of the study consisted of 246 final year undergraduate students in the Department of Mathematics/Statistics in Ignatius Ajuru University of Education from 2012/2013 to 2021/2022 academic sessions who offered MTH 421 which is Theory of Partial Differential Equations. MTH 421 examinations were written with paper and pen from the 2012/2013 to the 2017/2018 academic sessions. From 2018/2019 to 2021/2022, MTH 421 examinations were written as computer-based test. The sample size used was 196 final year students obtained by systematic random sampling technique. The instrument for data collection was Student Mathematics Score Sheets (SMSS). SMSS was used to collect the scores of students in MTH 421 from 2012/2013 to 2017/2018 for the Paper-Based Test (PBT) and from 2018/2019 to 2021/2022 for the Computer-Based Test (CBT). The instrument was validated by three lecturers in the Department of Mathematics/Statistics. SMSS contained items such as examination year, matriculation number, gender, programme, course code, paper-based test score and computer-based test score. The scores of students obtained from the SMSS were analysed using Cronbach Alpha to obtain a reliability coefficient of 0.85 for SMSS.

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Columbia Journal of Education and Social Sciences

Research Article

Mean and standard deviation were used to answer the four research questions while independent sample t-test was used to test the hypothesis at 5% level of significance.

Results

Research question one: What is the performance of students in Mathematics?

Table 1: Mean and standard deviation of undergraduate students' performance in Mathematics

n	Mean (%)	SD	Remark
196	67.18	17.49	High

From Table 1, the performance of undergraduate students in Mathematics is high (Mean= 67.18%, SD=17.49).

Research question two: What is the performance of students in mathematics evaluated using paper-based test?

Table 2: Mean and standard deviation of undergraduate students' performance evaluated using paper-based test

Exam Type	n	Mean (%)	SD	Remark
PBT	91	61.64	18.84	High

From Table 2, the performance of undergraduate students in mathematics evaluated using paper-based test is high (Mean= 61.64%, SD=18.84).

Research question three: What is the performance of students in mathematics evaluated with the computer-based test?

Table 3: Mean and standard deviation of undergraduate students' performance evaluated with computer-based test

Exam Type	n	Mean (%)	SD	Remark
CBT	105	71.99	14.70	Very High

From Table 3, the performance of students in mathematics evaluated with the computer-based test is very high (Mean= 71.99%, SD=14.70).

Research question four: What is the difference between the performance of students evaluated using PBT and CBT?

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Columbia Journal of Education and Social Sciences

Research Article

Table 4: Mean and standard deviation of the Mathematics performance of students evaluated using PBT and CBT

Exam Types	n	Mean (%)	SD	Difference	
				Mean	SD
PBT	91	61.64	18.84	10.00	4.14
CBT	105	71.64	14.70		

From Table 4, the difference between the performance of students evaluated using PBT and CBT is high (Mean=10.00%, SD=4.14) and in favour of the group evaluated with computer-based test.

Hypothesis one: There is no significant difference between the mathematics performance of students evaluated using paper-based test and computer-based test respectively.

Table 5: Summary of independent sample t-test analysis on the difference between the performance of students evaluated using PBT and CBT

Exam Type	n	Mean (%)	SD	F	df	t	Sig	Remark
PBT	91	61.64	18.84	5.41	194	-4.31	0.000	Significant
CBT	105	71.99	14.70					

Table 5 shows that there is a significant difference between the mathematics performance of students evaluated using paper-based test and computer-based test respectively ($t_{(194,\ 0.05)} = -4.31, p < 0.05$).

Discussion

From Table 1, the performance of undergraduate students in Mathematics is high. Undergraduate students of mathematics are performing well generally in their course of study. Similar findings were obtained by Otikor and Zalmon (2019), stating that the performance of undergraduate mathematics was high. Wonu and Zalmon (2019) confirmed that 71% of undergraduate mathematics students graduates on their programme out of which, 41% obtained first-class honour and second-class honour (upper division). From Table 2, the performance of undergraduate students in mathematics evaluated using paper-based test is high. Mehrens et al. (2022) reported significant variations in student performance across testing modalities. Zalmon et al. (2021) revealed that there is significant difference between the cognitive achievements of students in algebra when evaluated with different test types.

From Table 3, the performance of students in mathematics evaluated with the computer-based test is very high. The findings of Rodriguez-Garcia et al. (2023) reveal a nuanced landscape of performance differences between computer-based and paper-based mathematics assessments with statistically significant variations in student performance across testing platforms contrary to simplistic assumptions of technological equivalence. Thompson and Chen (2022) examined the interaction between technological mediation and mathematical problem-solving.

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Columbia Journal of Education and Social Sciences

Research Article

Key findings included: varied performance across different mathematical domains, significant impact of student technological self-efficacy and potential bias introduced by digital interface design. Patel and Williams (2023) explored the psychological aspects of testing modalities, identifying the following factors associated with computer-based test: increased test anxiety in computer-based environments, variations in student confidence across testing platforms and differential cognitive load between paper and digital testing formats.

From Table 4 and 5, the mathematics performance of undergraduate students' evaluated using computer-based test is higher than the performance of those evaluated with paper-based test. Students evaluated with computer-based test significantly outperformed their counterparts evaluated with the conventional paper-based test in mathematics. This results shows that there is a great transformation from the traditional mode of assessment to the modern mode using computer-based test with significant improvement in the performance of students evaluated with CBT. This significant improvement in the performance of students in mathematics in CBT could result from students' resolve to change their attitude to learning and discipline themselves to study, embarking on several problem-solving and drills with the positive mindset of passing their examinations since CBT will not give them the opportunity to commit examination malpractices. On the contrary, McClelland and Cuevas (2020) compared the performance of students in mathematics using PBT and CBT formats of testing, and reported that students performed better in PBT than CBT. The performances of students in paper-based test is sometimes influenced by examination malpractices. Controlling examination malpractice in PBT format is a challenging task. Related studies were conducted by Tella and Bashorun (2012), Wallace and Clariana (2002) and Organisation for Economic Co-operation and Development (2010).

Conclusion

This study comparatively analysed the performance of undergraduate students in mathematics evaluated using computer-based test and paper-based test. The result of the study shows that students evaluated with the innovative computer-based test significantly outperformed their counterparts assessed with the conventional paper-based test. The comparative analysis underscores the complex interplay between testing modalities and mathematical performance. While technological advancement offers promising assessment opportunities, careful consideration of individual differences and technological proficiencies remains paramount.

Recommendations

1. Undergraduate mathematics students should study hard to sustain and instead improve on their good performance.
2. The paper-based test is a reliable test instrument for evaluating student performance in mathematics and should be used where the computer-based test facilities are not adequately available to avoid undue examination stress on the students due to the process of queuing to use the few computer facilities available in schools for examination.

3. The computer-based test is very reliable to evaluate the performance of students in Mathematics when students are drilled with several related questions before the examination and it's recommended for use in classroom assessment to minimise examination malpractice.
4. Proprietors of learning institutions should build high capacity automated computer-based examination centres to control examination malpractice, reduce queuing to write computer-based test and enhancing the performance of students in mathematics in this digital age.
5. External examination bodies at all levels should upgrade to using the computer-based test in their examination conduct to foster academic excellence by rebuilding the reading culture in students and eradicating examination malpractices.

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