IMPACT OF COVID-19 ON THE ACADEMIC PERFORMANCE OF SCIENCE STUDENTS USING BAYESIAN MODEL

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ABSTRACT

Considering the emergence of the global COVID-19 pandemic, teaching and learning activities were interrupted for almost a year across the Senior Secondary Schools in Nigeria. This research work seeks to investigate and evaluate the degree of impact of COVID-19 on the academic performance of Science students from four (4) Science subjects; Mathematics, Physics, Chemistry and Biology using a Bayesian Hierarchical Linear Mixed Effects Model (BHLMEM) fitted to cross-sectional data. The Bayesian Model is designed for this application which allows student-specific error variances to vary across the Science subjects. The data collected was analyzed using Residual Maximum Likelihood in R package. It was clearly evident that COVID-19 had a huge impact on the academic performance of Science students in Secondary schools. Some recommendations were suggested to the educators that it is important for teachers to seamlessly integrate and infuse themselves into the cutting-edge paradigm shift of the 21st century known as digital mode of teaching, and they should train and guide the learners until they acclimatize to the ecosystem of online teaching.

Keywords: Bayesian, Impact, COVID-19, Academic performance, Bayesian model.

1. INTRODUCTION

1.1 Background to the Study

The name “Corona virus, also known as “COVID-19” comes from the Latin word “Corona”, meaning “Crown” or “Halo.” Under an electron microscope, it looks like it is surrounded by a Solar Corona. The novel Corona virus identified by the Chinese authorities on January 7, 2020 and was named SARS-CoV-2. It is a new strain that had not been previously identified in humans. Little is known about it, although human-to-human transmission has been confirmed (Aljazeera, 2020). It was quite

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bewildering to wake up to the sudden outbreak of COVID-19 pandemic that quaked in every sector across the globe. COVID-19 pandemic has affected all levels of educational system (Nicola et al. 2020). As at the end of April 2020, educational institutions shut down in 186 countries all over the world including Nigeria, affecting about 1.7 billion (approximately 74%) of enrolled students globally (UNESCO 2020). On the 23rd of March 2020, when the total confirmed case was 40, with one death, two recoveries and 37 active cases, the Federal Government of Nigeria temporarily shut down all schools in Nigeria in a bid to contain the spread of the Corona virus (BBC News, 2020). It is important to understand comprehensively how students' performance has been before the outbreak of COVID-19 and how it has altered the academic performance of the students after the year 2020, and to investigate the factors that potentially contributed to the changes. Due to the unique situation of COVID-19 and its profound societal and educational implications, there have been a few published articles discussing the COVID-19 repercussions, and the shutdown of educational institutions on the academic performance of students in Secondary Education.

Johnson et al. (2020) discovered that schools who were struggling with various challenges adopted new instructional methods and strategies. And this resulted to the need for planning and designing online learning avenue in advance for any future outbreaks of global pandemics and other crises (Korkmaz and Toraman, 2020).

Considering some other countries in the world that implemented various e-learning strategies to lessen the impact of COVID-19 on Science Education and shifted towards digital education during the pandemic.

China launched a nationwide home-schooling plan and TV broadcasts providing continuity in education despite school closures (Yunusa et al. 2021). France offered devices to students lacking computers and utilized a platform called "My Class at Home" for virtual learning.

South Africa initiated the STEM Lockdown Digital School", where teachers conducted live-streamed lessons on social media platforms. Estonia collaborated with foundations to support distance learning, while Portugal used postal services to deliver educational materials to students without internet access (Oluwagbemiga et al. 2022).

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1.2 Literature Review

Exposito and Principi (2020) said that the national lockdown of educational institutions across Nigeria has caused a major interruption and setback in students' progressive learning: disruptions in academic programs, suspension of internal and external examinations, creating lacunae in teaching and learning, and it has probably caused work force shortage in the institutions because of death caused by COVID-19.

So many countries in the wake of the COVID-19 outbreak and its associate were able to adopt effective measures to curb the effect of disruption of regular schooling during the lockdown. The Chinese government, for instance, provided computers for low income households, offered mobile data and telecommunication subsidies so as to enable their children to participate in virtual learning (Hussain, 2020).

COVID-19 has a profound negative impact on science students mostly because they need practical participation, demonstration and observation of outcomes (Noah & Gbemisola, 2020).

Hussain (2020) also discovered that in France, students who do not have access to computers were lent the devices they needed. Portugal, on its part, partnered with postal services to deliver working sheet to a student who does not have access to the internet at home.

Adelakun (2020) submitted that during the lockdown, some educational facilities in schools like science laboratories got dilapidated as a result of lack of use for a long period of time.

Olayiwola et al. (2024) derived a mathematical modeling of COVID-19 treatment strategies utilizing Lapalce Adomian decomposition method to assess the effectiveness of recent advancements in COVID-19 treatment in curbing the spread of the virus. The accuracy of the model was confirmed through ratio test, and their findings results in rapid elimination of COVID-19.

Yunus and Olayiwola (2024) underscored the crucial role of COVID-19 vaccinations in managing the pandemic by employing a fractional-order mathematical modeling approach and the solution to the model was derived through Laplace Adomian Decomposition Method (LADM). The study concludes that implementing a vaccination strategy in an integer order proves to be the most effective approach to controlling the spread of COVID-19.

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Alaje and Olayiwola (2023) adopted the use of numerical solutions with proposed modified initial guess homotopy perturbation method. The study used this efficient method to solve a fractional-order diffusive epidemic model of COVID-19 that incorporates vaccination and is applied to investigate the spatiotemporal spread of COVID-19.

Rahman et al. (2021) carried out a study on the mathematical modeling of COVID-19 with Caputo-Fabrizio fractional-order derivative by exploiting the approach of fixed-point theory utilizing LADM and the results showed better results in controlling the outbreaks.

Tassadiq et al. (2024) investigated using comparative analysis of classical and Caputo models for COVID-19 spread, and the study verified a Caputo operator-based fractional order epidemiological model of the Susceptible–Asymptomatic–Infected–Vaccinated–Removed (SAIVR) type. The analysis of the study includes the fractional system of Hyers-Ulam-Rassias (HUR) stability and stable states indicating that the system best fits real-life medical data for infectious diseases.

Therefore, it is quite important to understand comprehensively how students' performance has been before and after the outbreak of COVID-19, and there is a need to investigate the impact of the COVID-19 pandemic on the academic performance of Senior Secondary School students in science subjects in Nigeria through the use of a Bayesian statistical model. The main aim of this study is to investigate the impact of COVID-19 on the academic performance of Senior Secondary School students in science subjects, and to evaluate the difference between the academic performance of male and female Science students, and to determine the academic performance of Private and Public-School Science students during pre and post COVID-19 using Bayesian Hierarchical Linear Mixed Effects Model.

2. METHODS

2.1 Bayes' Theorem

Bayes' theorem could be seen as a way of understanding a hypothesis to show if it is true and affected by new data in mathematical notation,

$$P(A|B) = \frac{P(B|A).P(A)}{P(B)} \qquad (2.1)$$

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where,

A is the hypothesis we are interested in; and

B represents the new data.

P (A | B) is the likelihood (posterior probability)

P (B) is the evidence (prior probability)

Since B is fixed for a given set of data as:

$P(A|B) \propto P(B|A)P(A)$, P(A| B) is proportional to the product of the likelihood of the new data given the hypothesis, i.e., $Posterior = \frac{Likelihood \times Prior}{Evidence}$.

In this study, a Bayesian Statistical Model was proposed, which is also known as Bayesian Hierarchical Linear Mixed Effect Model (BHLMEM) to evaluate the impact of the sudden pandemic on the academic performance of Senior Secondary School students in science subjects. This analysis can be reviewed because it started with some summarized statistics followed by a fully BHLMEM. The last decade had witnessed noticeable changes in the way experimental data are analyzed in the education sector and the educative changes. In particular, there has been a paradigm shift from analysis of variance (ANOVA) to linear mixed models (LMM), also known as multilevel (hierarchical) models (MLMs) fitted into Restricted (Residual) Maximum Likelihood; spurred by the spreading use of data-oriented programming languages such as R software package (R Core Team, 2017), and by the enthusiasm of its active, transformative and ever-growing community. This shift has been further sustained by the current transition of data analysis in sciences, with researchers evolving from a widely criticized point-hypothesis mechanical testing, and transiting into an approach that emphasizes parameter estimation, model comparison, and continuous model expansion. BHMLEM offers great flexibility in the sense that it can model statistical phenomena that occur on and at different levels. This is done by fitting models that include both fixed (constant) and random (varying) effects.

Among other advantageous procedures, the use of BHLMEM allows the ease and eventuality to generalize the results to unobserved levels of the groups existing in the data (Janssen, 2012).

2.2 The Linear Mixed Effects Model

Let Y_it be the raw marks in percent for the *i*th student *(i* = 1, . . ., *k)* evaluated at time

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t $(t = 1, \ldots, n)$ in a particular subject. The subscript t represents a series of evaluations conducted over time from assignments, quizzes, continuous assessment tests, projects and examinations.

Let X_it be another variable measured at time t for the ith student which can explain the variation in Y_it. We consider the following linear mixed effects model:

$$Y_it = \beta_0 i + \beta_1 ixit + \epsilon_i t \qquad (2.2)$$

$$\begin{cases} where & 1 \quad average \quad marks; \\ & 0 \quad otherwise, \end{cases}$$

where;

Equation 2.1 is singular regression with a variance components model.

Y_it is the raw marks in percent for the students

X_it is the measured variable at time t for the ith student

i is the number of students

t is the number of years used to assess and evaluate the series of examinations. And

$\epsilon_i t$ ~ Normal $(0, \sigma^2)$ with student-specific error variance σ^2.

The sampling distribution of Y_it is:

$$Y_it = \{\beta_0 i, \beta_1 i, \sigma^2 \sim Normal(\beta_0 i + \beta_1 ix_it, \sigma^2)\} \qquad (2.3)$$

In this model, β_{0i} and $\beta_{0i}+ \beta_{1i}$are the average marks of the ith student before and after COVID-19. Here, $\beta_1 i$ is the difference of average marks before and after COVID-19; for the ith student. Let $\beta i = (\beta_{0i}, \beta_{0i})^T$ represents the vector of regression coefficients for the ith student. We assume that the ith student is a randomly and independently selected students from the pool of students in a specific subject in some selected Senior Secondary Schools in Kwali Area Council. This leads to considering the sampling distribution for $\boldsymbol{\beta_i}$ as:

$$\beta i|\Sigma \sim MultivariateNormal(\theta, \Sigma) \;, \qquad (2.4)$$

where $\boldsymbol{\theta} = (\theta_0, \theta_1)^T$ and Σ is the variance-covariance matrix. This part of the model explains that:

θ_0 and $\theta_0 + \theta_1$ are the average marks of all students in one of the Science subjects.

The likelihood function for the parameters of the linear mixed effects model is:

$$L\,(\boldsymbol{\beta}_1, \ldots \boldsymbol{\beta}_k, \sigma_1^2, \ldots, \sigma_k^2, \boldsymbol{\theta}, \Sigma, v_0, \sigma_0^2 |\, \mathbf{y}_1, \ldots, \mathbf{y}_k, \boldsymbol{x}_1, \ldots, \boldsymbol{x}_k)$$

Note that the likelihood function provides information contained in the data for the unknown parameters of interests.

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2.3 Method of Estimation

Scientific data are often complicated and messy if we are trying to fix complicated models with many parameters. On top of that, our data points might not be truly independent. This is why linear mixed effect models were developed to deal with such messy data and allow us to use all our data, even when we have low sample sizes, structured data, combination of fixed and random effects and many covariates to fit and to crown it all, mixed models allow us to save degrees of freedom compared to running standard linear models.

2.4 The Prior Distributions

The prior distribution of a parameter represents experimenter's prior belief via hyper-parameters. It was noted that the prior belief should be unbiased: a belief which reflects the expected truth of the system that generates the data. The prior distribution for the subject-specific error variance σ_0^2 is considered as:

$$\sigma_0^2 \sim Gamma(\propto_1, \propto_2), \qquad (2.5)$$

where, the prior belief regarding σ_0^2 is represented by the hyper-parameters:

$\propto_{1:}$ the shape parameter, and $\propto_{2:}$ the rate parameter

Specifically, the expected prior belief about σ_0^2 is expressed as $E\ (\sigma_0^2) = \propto_1/\propto_2$. We restrict v_0 to be a whole number and choose the prior on v_0 to be a discrete analogue of exponential distribution on {1, 2, 3, . . .} as following:

$$P(\nu_0) \propto (1 - e^{-\propto_3})e^{-\propto_3} v_0 \qquad (2.6)$$

where, $\propto_3$ reflects the strength of prior belief about v_0. Specifically, small values of $\propto_3$ represent weak belief about v_0 and vice versa. The parameter vector for the subject-specific mean $\boldsymbol{\theta}$ is considered to follow the following distribution

$$\theta \sim MultivariateNormal(\theta_0, \Sigma_0) \qquad (2.7)$$

The prior belief about the subject-specific mean vector is considered to be $\boldsymbol{\theta}_0$ (i.e., $E\ (\boldsymbol{\theta}) = \boldsymbol{\theta}_0$) and the strength of the prior belief is represented by the variance-covariance matrix Σ_0.

Here, Σ_0 is a positive-definite matrix, and the prior distribution corresponding to the variance-covariance matrix Σ of the subject specific mean vector $\boldsymbol{\theta}$ is:

$$\Sigma \sim Inverse - Wishart(\eta_0, S_0^{-1}) \qquad (2.8)$$

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where the prior belief about Σ is represented by S_0 (i.e., $E(\Sigma) = S_0/(\eta_0 - d - 1)$, where d be the dimension of $\boldsymbol{\theta}$) and the strength of prior belief is represented by η_0.

2.5 The Posterior Distributions

After collecting data, we combine the information from the data with prior belief to obtain posterior belief. The posterior distribution of Σ is Inverse-Wishart which is obtained via Equations (2.4) and (2.8) as following:

$$\Sigma|\theta, \beta_1, \ldots, \beta_k \sim Inverse - Wishart(\nu_0 + k, (S_\theta + S_0^{-1}) \quad (2.9)$$

where, $$S_\theta = \Sigma_{i=1}(\beta_i – \theta)(\beta_i – \theta)T \quad (2.10)$$

2.6 Ordinary Least Square and Assumption of Hierarchical Linear Mixed Effects Model

The Assumption of Linearity, that is, the Ordinary Least Square (OLS) Assumption was proposed to fit a hierarchical linear mixed model using Bayesian Statistics. The OLS in hierarchical linear mixed model is a regression-based analysis that takes the multilevel structure of the data into account. When you use the model for hypothetical situation, you are likely to get inaccurate results. Hence, you should always plot a graph of observed predicted values.

These are the following assumptions of hierarchical linear mixed effects model, viz:

1. Data does not need to meet the homogeneity of regression slopes requirement.
2. The explanatory variables are related linearly to the response.
3. The data must be linear and normal.
4. Equal variances on groups must be met.
5. The errors have constant variance.
6. The errors are independent.
7. The errors are normally distributed.

3. RESULTS

The data used for this study was a secondary source of data and these were collected from six (6) different schools in Kwali Area Council in FCT-Abuja for three (3) years.

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Table 1. Selected Schools, Selected Science Subjects, Number of Students, Percentage of Disengaged Students, and Percentage of Missing Students' Marks

Subject	Number of Students	Disengaged students (%)	Missing marks (%)
Biology	52	0.00	5.14
Chemistry	43	3.47	3.73
Mathematics	67	2.68	3.78
Physics	58	1.75	3.26

The Science subjects focused on among others are Mathematics, Physics, Biology, and Chemistry. The percentage of disengaged students vary from 0.00% to 3.47% (i.e., students that enrolled from the beginning of an academic session but left the school due to relocation or other reasons). Since there were no marks available for the evaluation components for the disengaged students after, we excluded them from further analysis. The percentage of missing marks is defined as the percentage of missing evaluation components relative to all evaluation components for the remaining students in a subject. These numbers vary from 3.26% to 5.14%.

Table 2. Impacts of COVID-19 on the Academic Performance of Senior

Subject	Performance(%) in 2019	Performance(%) in 2020	Performance(%) in 2021	Percentage(%) Rise↑/Drop↓
Biology	56.85	52.95	54	-2.85
Chemistry	54.05	50.6	54.6	+0.55
Mathematics	60.4	41.05	50.25	-10.15
Physics	62.8	58.2	50.25	-12.55

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Secondary School Students in Science Subjects

The mathematical formula used for this calculation that resulted into a percentage rise or drop is analysed below:

Percentage (%) rise/drop = (Y3 - Y2) - (Y1 - Y2) (3.1)

Biology: (54.00 - 52.95) - (56.85 - 52.95) = 1.05 - 3.90 = -2.85

Chemistry: (54.60 - 50.60) - (54.05 - 50.60) = 4.00 - 3.45 = 0.55

Mathematics: (50.25 - 41.05) - (60.40 - 41.05) = 9.20 - 19.35 = -10.15

Physics: (50.25 - 58.20) - (62.80 - 58.20) = -7.95 - 4.60 = -12.55

Chemistry recorded a faint significant improvement in performance levels with a positive result of +0.55% rise in pass rate while Biology, Mathematics, and Physics declined with negative results of -2.85%, -10.15%, and -12.55% respectively over a period of three years. However, Science subjects recorded a significant percentage drop in performance except for Chemistry which recorded a slight significant percentage rise in performance.

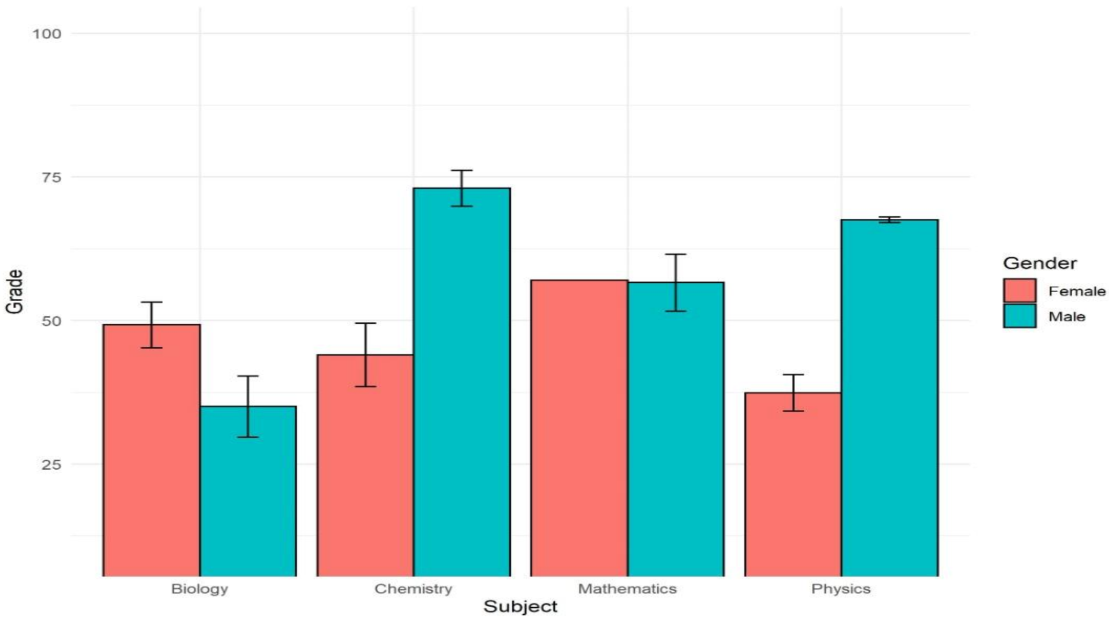

Figure 1. Examining the Difference between the Academic Performances of Male and Female Science Students during Pre and Post COVID-19.

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From "Figure 1", it is observed that the performance of both male (35%) and female (49%) students in Biology was below average (42%). In Chemistry, the performance of both male (35%) and female (49%) students was a bit encouraging because it was far above average. In Mathematics, it was slightly an above average (57.75%) performance of both male (57.5%) and female (58%) students, and in Physics, it was a below average (47.75%) performance of both male (65.5%) and female (30%).

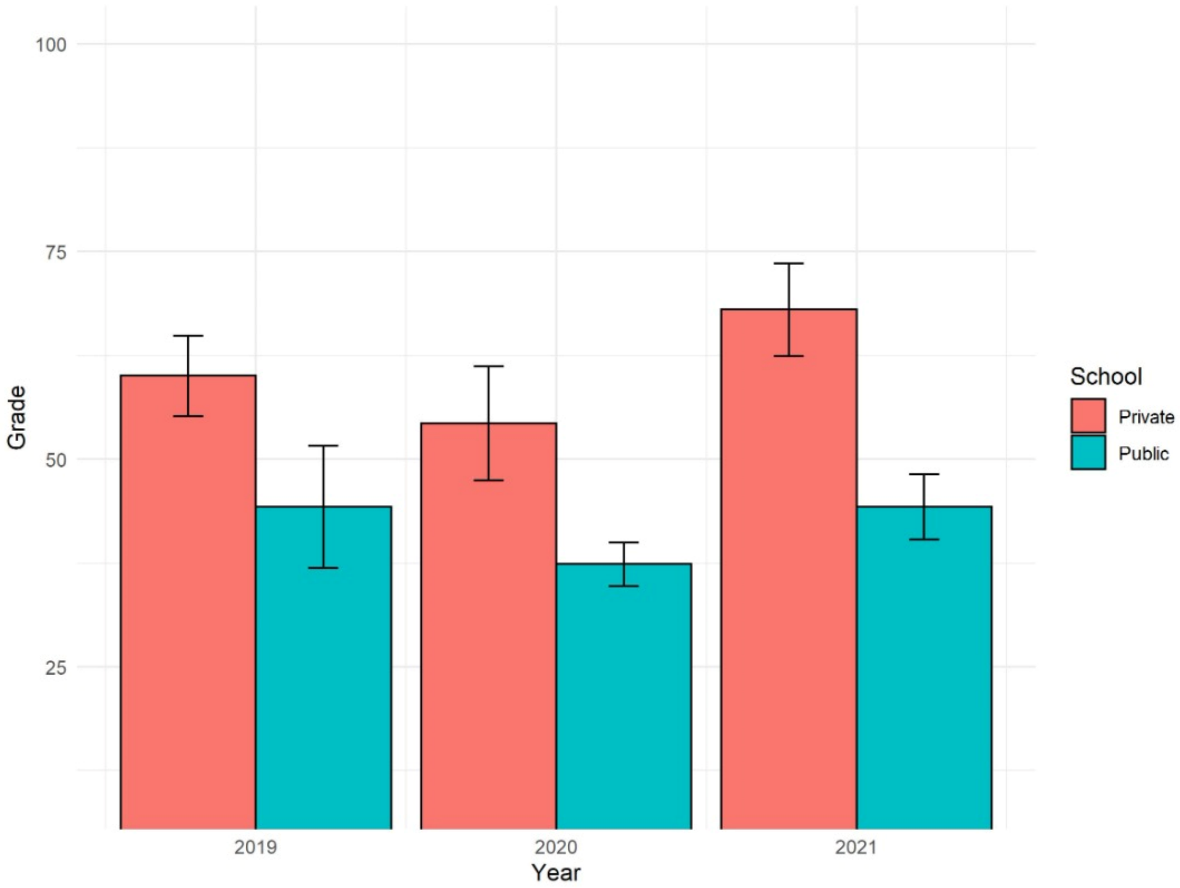

Figure 2.1. Determining the Difference between the Academic Performances of Science Students of Private and Public Schools during Pre and Post COVID-19.

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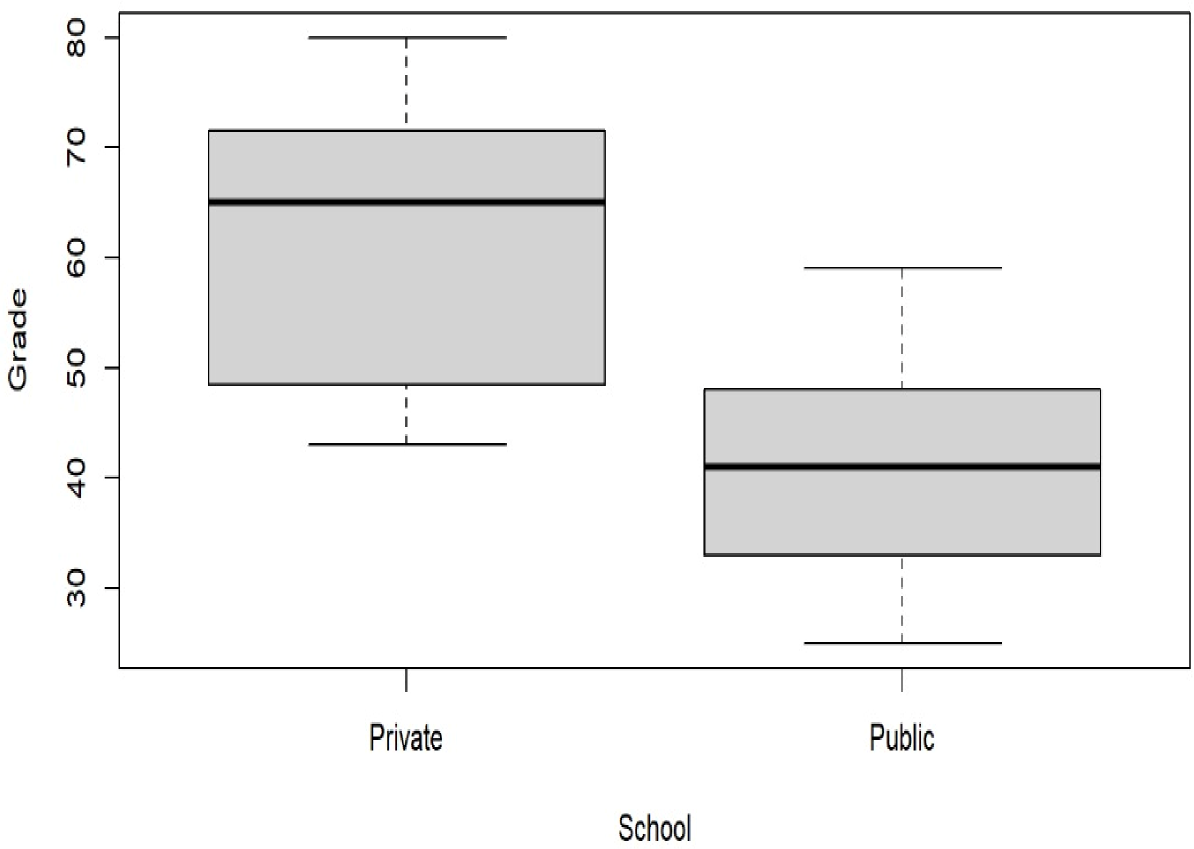

Figure 2.2. Determining the Difference between the Academic Performances of Science Students of Private and Public School during Pre and Post COVID-19.

From “Figure 2.1”, in 2019, before COVID-19, the performance of the Private School students in Science subjects was above average (61.75%), while that of the Public School students in Science subjects was below average (43.75%) on a scale of 0-100. In 2020, the outcome of the performance of the Private School students in Science subjects was above average (52.75%), while that of the Public School students in Science subjects was below average (37.75%).

And in 2021, after COVID-19, the performance of the Private School students in Science subjects was above average (67.75%), while that of the Public School students in Science subjects was below average (43.75%). In “Figure 2.2”, there is also a clear indication showing that there is a significant difference between the

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academic performance of Science students of Private and Public Schools during pre and post COVID-19.

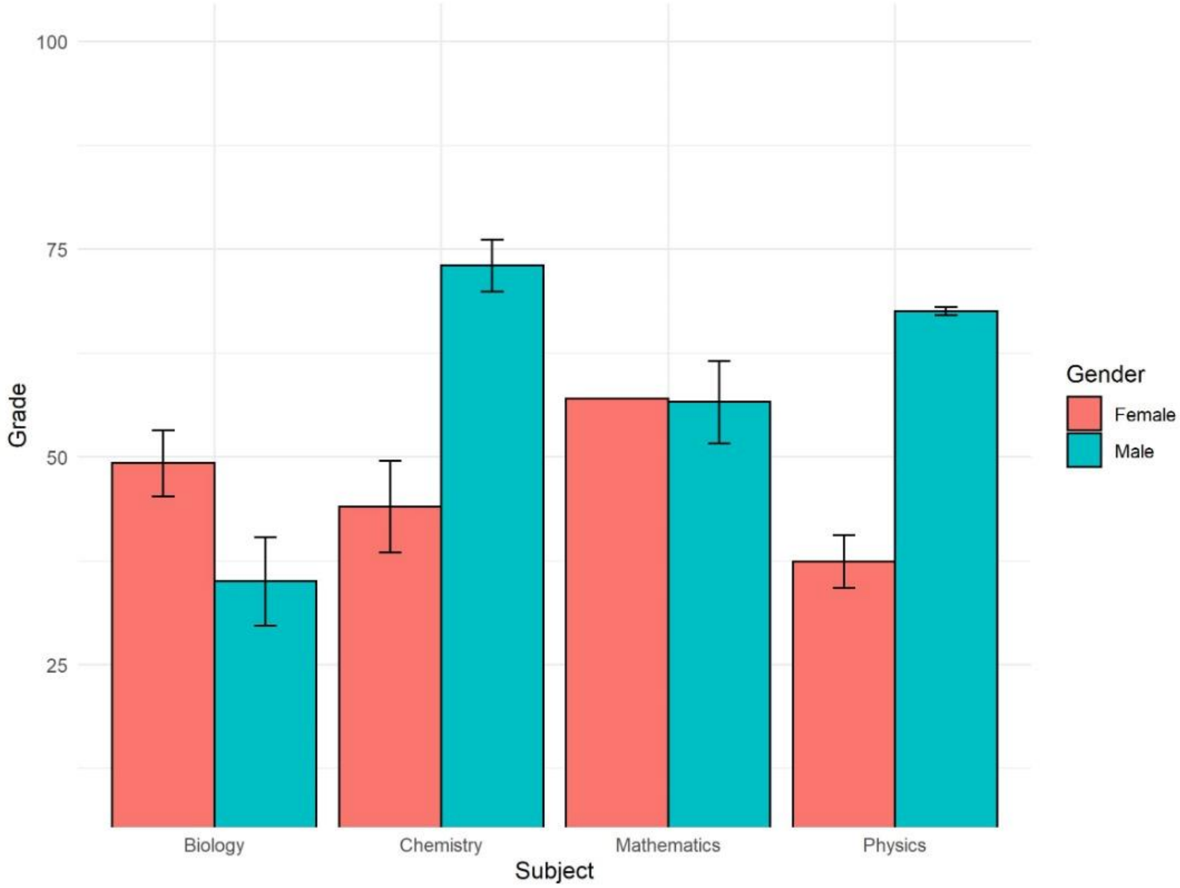

Figure 3. Investigating Whether the Academic Performance of Senior Secondary School Students Get Stronger or Weaker

In “Figure 3”, among the four (4) Science subjects selected for this study, both decreasing and increasing trends in the students’ scores were observed. Specifically, there is a decrease in the scores shown in the subjects such as Biology and Physics.

4. DISCUSSSION OF RESULTS

The data used for this study was a secondary source of data and these were collected from six (6) different schools. The researcher collected these data in three (3) Private Schools and three (3) Public Schools in Kwali Area Council in FCT-Abuja. The data for yearly academic session for three (3) years, i.e. 2019, 2020 and 2021.

Data collected from six (6) Senior Secondary Schools in Kwali Area Council in FCT-Abuja is a steady decrease except for Chemistry; and the result shows a

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slight positive result, an overall situation which is signifying a negative impact on the academic performance of Science students. The Science subjects focused on among others are Mathematics, Physics, Biology, and Chemistry. In view of the six (6) Senior Secondary schools selected for this study, the data for Science students of a set or class was collected for the purpose of this study. The academic performance of Science students is characterized by cumulative results for each session, which are derived from projects, assignments, continuous assessment tests, and exam scores. The cumulative results were used to assess and quantify the academic abilities and performance in Science students due to the impact of COVID-19. Among the four (4) Science subjects selected for this study, both decreasing and increasing trends in the students' scores were observed. Specifically, there is a decrease in the scores shown in the subjects such as Biology and Physics requiring lower-level cognitive skills according to Bloom's Taxonomy of Knowledge, whereas there is an increase in the scores shown in the subjects such as Chemistry and Mathematics requiring either calculations or higher-level cognitive skills, which is in accordance to (Federal Department of Education (FDE), 2017).

5. CONCLUSION AND RECOMMENDATION

On the basis of this finding, we can therefore conclude by stating that:

1. The emergence of COVID-19 had a severe impact on the academic performance of Senior Secondary School students in Science subjects.

2. The sudden appearance of COVID-19 had a huge negative impact on the academic performance of both male and female students in the Senior Secondary School in Science subjects.

3. The novel COVID-19 had a great negative impact on the academic performance of Science students in Public and Private Secondary Schools.

4. It was investigated that the impact of COVID-19 led to the reduction of scores in the academic performance of some of the Senior Secondary School students in science subjects, while there was increase in some of the academic performance of

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Senior Secondary School students in Science subjects, thereby leading to inconsistent trend of scores across all the selected Science subjects.

The following recommendations were made to minimize the impact of COVID-19 among Senior Secondary School students offering Science subjects based on the findings of this study:

1. Policy makers, school administrators, teachers, as well as students, must be trained on how to handle and use online educational devices.

2. Teachers should add to their professional proficient skills by developing their technological skills in learning the 21st century e-learning mode of teaching so as to impact the students until they adapt to online teaching and learning environment.

3. Government should see the need to build good schools and equip them with modern digital facilities that can aid online education by providing digital devices as well as internet service provider and its connections.

4. Teachers of Science subject should be focused to learn the new digital and technological skills, as this would make them to be ready ahead of similar future events like COVID-19; as this would inspire the students and brings about no delay in their academic progress.

5. Adopting the use of technology in the classroom is not just sufficient, but educational managers and leaders should also take cognizance of changing conditions, flexibility in approaches, and boosting student engagement.

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