Comparison of Online Learning during the Covid-19 pandemic against the traditional face-to-face learning experience for a STEM related subject, Analytical Mathematics

Original Research Article

Abstract

The Coronavirus (Covid-19) pandemic put a halt provisionally to face-to-face teaching throughout the educational sector impeding in addition, university students from receiving their traditional on campus teaching learning experience. Educators, academics, and the higher institutional authorities had to act fast and change their mode of teaching delivery to online platforms, with many students transferring their learning habits and customs to various online mediums and tools. In view of the struggles and adjustments many students underwent with this new method of teaching, a research study was conducted to identify whether online learning had an effect on student performance for a Science, Technology, Engineering and Mathematics (STEM) related module. On this purpose, this paper evaluates different statistical test measures to compare the two different teaching techniques adopted by a university foundation level module, Analytical Mathematics. Results from the pursued quantitative analysis show a decrease in the success of students' performance whilst receiving online teaching, suggesting a lesser impact on improved learning compared to the customary face-to-face delivery for this specific module. With regards to engagement, observations from the qualitative analysis of the study show a lack of involvement and participation from students with their lecturer and peers whilst in an online environment, echoing its influence on student performance. The deductions of the analyses of this study, emphasize that the necessary transition to online delivery and learning during the pandemic did lead to a challenging and negative experience on students and their performance for this STEM related subject.

Keywords: Mathematics-STEM; Coronavirus; online and face-to-face learning

2010 Mathematics Subject Classification: 53C25; 83C05; 57N16

1 Introduction

In December 2019, a virus was found in China which later caused a global pandemic in March 2020, causing everyone's daily lives to change [(1)]. Educational institutions had to change their ways of operations, allowing for online teaching to be introduced, thus replacing temporarily face-to-face teaching. This study will begin with an overview as to the different ways educators adapted in their

teaching and will reference the challenges faced with this change of teaching environment. It was a rapid transition from traditional to online teaching whereby assignments and examinations were also submitted electronically and teaching videos became a live online or pre-recorded phenomenon [(2)].

The world was put on hold during Covid 19 and the education sector was one of the hardest to be hit due to this pandemic. The students were forced to follow their courses through online classes from their homes [(3)]. The Higher Education Providers (HEP) were put in a position to introduce new methods to deliver lessons with the tuition fees of students remaining as for a face-to-face experience [(4)]. Many students around the world suffered adversely due to the pandemic including the millions of students in the UK.

The Universities had limited time and resources to come up with a plan to give the same education for their students. They also had to face certain issues which were supposed to be addressed beforehand. The revenue from the international students who come to the country for higher education plays a vital rule towards the UK economy [(5)] and the pandemic restricted the arrival of students from other countries and hence HEP had to satisfy the students from all around the world. The pressure was immense to plan and execute within the limited time restrictions.

During this unprecedented time around the world, the importance and validity of an analysis on these two types of forms of learning is key to build a similar environment for the students to rely on in the future. With the whole world going into lockdown in 2019, UK was also compelled to follow the rules to prevent spreading of the virus. With all the disruptions, the government organised funds and aids to help all the sectors around country. The education sector moved completely to online teaching and the students were expected to follow classes from their home surroundings [(6)].

Many students immediately faced issues as they did not have the necessary technological tools and mature internet connection to attend online classes [(7)]. Students were forced to adapt to these changes quickly and yet some struggled to cope with the stress it caused, experiencing also perhaps for the first time examinations online [(8)].

The face-to-face traditional way of teaching has been employed for many years everywhere whereby students physically attend the classes and lectures. The educators teach and explain the subject material making sure that students understand the concepts well. In this environment, students clarify their queries and get answers, feedback straight away without any delay in time [(9)]. The traditional classes take place at a specific time and location where students need to be physically present in order to attend them. Students are also given opportunities to participate in group activities and presentations to improve their communication and group work skills.

Online teaching in most subjects is a fairly new approach of virtual learning in the higher education sector. Here the academics or educators would normally pre-record or record lectures in immediate time with students being able to attend their classes from home through an online platform. In the case of missing an online lecture, this could be watched later thus providing a very flexible learning environment [(10)]. The benefit of this teaching method is that it can help students who have other responsibilities whilst at home to manage the time between the studies and other tasks. The economical situations can affect a student's online learning vastly and many even faced hardships with using digital devices and tools [(11)].

The main objective of this paper is to understand the two forms of teaching presented to students for this module and how the adopted methods had an impact on their academic performance towards their education as well as highlighting its drawbacks.

1.1 Literature Review

According to Chiodini [(12)] due to the pandemic many sectors around the world were affected including the education sector. Many developing countries faced many technological and financial pressure to provide a better education even during the tough times of the pandemic [(13)]. As the whole world was in lockdown many students' mental well being in learning was deteriorating and this put more pressure on the education providers to tackle this issue [(14)]. There are many issues

students had to endure in their online learning during the period of the pandemic. In some hard hit countries, the students did not have proper internet connection and the necessary tools to continue their studies effectively. In some countries many had to pay more money to get the required data for the internet provider to download large files including notes and videos. Many, unfortunately, faced financial struggles to pay for these additional technological requirements.

Traditional, blended and online learning are examples of types of teaching. The concept of a traditional way of teaching is considered here as face-to-face with the presence of educators and students [(15)]. Educators prepare lectures beforehand and give assessments to students after the content is delivered and it is believed that there is more engagement amongst academics and students in this manner [(16)]. The educator provides tips to help develop students' knowledge and students can sort out queries without delay by speaking to the educator directly. In this type of teaching, group activities can occur which allows students to develop skills such as group work and communication [(17)]. In addition with this type of teaching environment, the direct supervision of educators can help the students positively to grasp the concepts [(18)].

According to Alonso et al. [(19)] and Holenko et al. [(20)] the most effective method of teaching is that of a blended learning approach, which combines live e-learning, self study, and face-to-face traditional teaching delivery. Blended teaching is increasingly showing dependency on e-learning whereby the use of technology like internet, Information and Communication and media are used to deliver this way of teaching. During online delivery, educators may provide live online or pre-recorded lectures which students can watch at their own time at home and may pause, forward or rewind the recording when they wish [(21)]. This type of teaching allows students to use technology in their learning and it is the main platform for the communication between students and educators. Communication and course design play a vital role in the online learning courses [(22)]. Online mathematics education poses particular challenges in terms of both the hardware and software necessary for effective teaching, due to issues with mathematical symbols and notation, among others [(23)]. Flipped classroom is another type of blended teaching where students can watch videos or look at resources before coming to lectures [(24)]. Although online/e-learning techniques may have positive effects on students' learning experience, there is still limited evidence about how this works in mathematically related subjects [(25)], hence this paper compliments existing literature and provides a comparison of online against traditional using statistical analysis on students' performance during the pandemic.

In this 21st century, especially after the pandemic many institutions are contemplating of combining both traditional and online learning methods towards their teachings delivery [(26)]. According to Moorhouse [(27)], the educators faced challenges during this shift of teaching methods and perhaps in the future, academics can learn from the drawbacks faced and provide a more successful teaching environment for all. For instance, in the article by Ortiz [(28)], the author explains about the difficulties the educator faced when preparing and teaching students online. Thus this transition of teaching from face-to-face to online has to be smooth and lucrative for both students and the lecturers.

2 Methodology

An empirical and statistical evaluation into these two different teaching techniques, were considered for the university foundation level module called 'Analytical Mathematics'. With the help of questionnaires for qualitative analysis and data gathered from exams of two consecutive academic years for quantitative purpose, a comparison of online learning during the pandemic against the traditional face-to-face learning delivery is presented to examine their effects on student performance. In addition, the quantitative analysis process consisted of examining the following cases:

(I) Comparison of results of Academic Year 2019/2020 vs Academic Year 2020/2021

Initially results of two cohorts of students were considered from the Academic Years 2019/2020 who received the traditional teaching, and 2020/2021 who received online teaching. Group A (Academic

year 2019/20) had a sample size 17 and Group B (Academic year 2020/21) had a sample size of 16.

(II) Comparison of results within the same cohort, Academic Year 2020/2021

In order to tackle the issue of perhaps different level of students' entrance abilities, a supplementary analysis was performed. Specifically, for the same module a topic from the syllabus was chosen to perform a comparison for the two different modes of learning environment. "Simultaneous Equations", a chapter in Basic Algebra that is not too cumbersome or too advanced to comprehend, as it deals with solving a linear system of equations was extracted from the syllabus to analyse the effect of this intervention way of teaching. For the fairness of results the class was split into two groups where one group resumed with its online teaching and the other group experienced face-to-face teaching only for the aforementioned chapter. The online group continued to be taught online incorporating pre-recorded videos, online lecture notes, online discussion forums and problem sheets and then the other group was taught by the lecturer through the traditional face-to-face environment for the duration of the topic. A written assessment in the form of an examination was given at the end of both teaching deliveries of this chapter in order to compare the impact on student performance.

2.1 Software and Results Processing

For the qualitative component of this paper, the data were inputted into Excel and R studio for a sound analysis. The graphs of each question were plotted for descriptive purpose. This gives a preliminary viewpoint to compare the two factors, in order to compliment the final outcomes. Measures of central tendency were needed to provide the foundations for further analysis. The R studio was then used for comparing the two data sets obtained from the student performance on the chosen topic of the module for two consecutive years. One with the face-to-face teaching during the year 2019/2020 and the other with the online teaching during the year 2020/2021.

3 Results and Discussion

3.1 Statistical Measures for Analysis

The obtained data was inputted into R and different tests were calculated to identify the most effective mode of teaching for the students. Likelihood ratio, t-test, chi-squared test are chosen and a performance ratio is also calculated to provide validity. The likelihood ratio in effect produces chi-squared test value with the p- values. Furthermore, a hypothesis testing is included where the null and alternative hypothesis are considered for the two different Academic Years 2019/2020 vs 2020/2021 as:

H_0: There is no difference in the mean assessment results of the two cohorts, Academic Years 2019/2020 vs 2020/2021.

H_1: There is a difference in the mean assessment results of the two cohorts, Academic Years 2019/2020 vs 2020/2021.

Depending on the statistical outcome the significance of this test is given, based on the significance level allocated. In addition, a hypothesis testing is also performed for the results of the test from the same cohort, taken on simultaneous equations, of the Academic Year 2020/2021 where they were divided into two groups of similar competencies and were taught through both methods separately. The null and alternative hypothesis considered for this instance are;

H_0: There is no difference in the mean assessment results of the two teaching methods for the same cohort.

H_1: There is a difference in the mean assessment results of the two teaching methods for the same cohort.

The effect size which is used to give valid evidence towards the considered hypothesis is found and is calculated using the relation below [(29; 30)],

$$effect\ size = \frac{Difference\ of\ the\ means\ between\ the\ two\ groups}{Pooled\ standard\ deviation}$$

To add to the statistical analysis of this paper, a consideration of the performance ratio is chosen to exemplify the difference if any of the performance of students on simultaneous equations comparative to the rest of the questions of the final assessment [(17)],

$$Performance\ Ratio = \frac{Total\ \%marks\ from\ simultaneous\ equation\ question}{Total\ \%marks\ from\ rest\ of\ the\ questions\ in\ the\ exam}$$

3.2 (I) Analysis of results of Academic Year 2019/2020 vs Academic Year 2020/2021

Initially box plots summarising the measures of central tendency and dispersion for the accumulated data were constructed and presented as Figure 1 below.

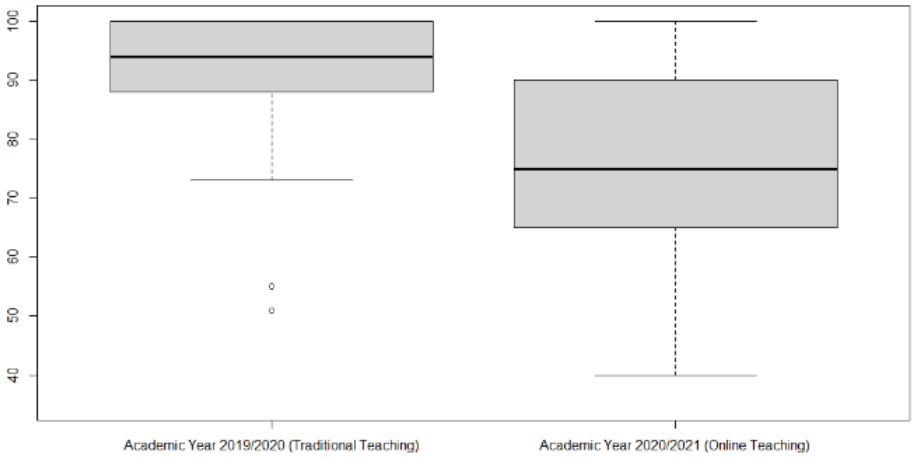

Figure 1. Box plots of Traditional face-to-face and Online teachings

The figure above depicts the impact effect of traditional face-to-face teaching compared to online teaching based on students' assessment results. It is evident that students achieved higher results in the academic year where traditional teaching was dominant.

Quantitative Analysis : (a) t-test

A t-test is a statistical method which provides with evidence to show whether the considered data set can agree or disagree with the null or alternative hypothesis focused in this paper. This test particularly studies whether there is any difference between the two independent groups and performing t-testing, the following results are tabulated, as shown in Table 1.

Table 1: Results of t-test

	Values:
t	2.5481
Significant Value	0.05
Degrees of Freedom	31
p value	0.01692

As the p value is less than the significance level, 0.05, the null hypothesis is rejected and thus accepting that there is a difference in the mean assessment results of the two cohorts.

(b) Chi-Squared test

The two independent groups studied here are used for the chi-squared test and the data inserted into R in order to complete the analysis. The following table, Table 2, presents these outputs.

Table 2: Results of Chi-Squared test

	Values:
$\chi - squared$	119.34
Significant Value	0.05
Degrees of Freedom	31
p value	$<$ 2e-16

The p value shown in the above table is much less than the significance level 0.05. Thus null hypothesis will be rejected again proving the validation of presence of a difference in mean between the two cohorts. In order to compliment statistical hypothesis testing, the effect size was found to take the value of 0.31, which under the guidelines of Cohen [(31)], this suggests a medium effect for the group of data. Therefore, around approximately 63% of the values in the mean of the traditional teaching results fall above the average of the mean online teaching results.

(c) Performance Ratio

The performance ratio was obtained by comparing the question relating to simultaneous equation against the other questions of the assessments over the two Academic Years. The two groups representing the consecutive academic years were again considered and each ratio value was obtained for all the students. The figure below portrays the performance ratio values for the two analogous groups. It is clear that, group A's ratio values show that more students performed better in the simultaneous equations questions compared to the remaining questions of the exam.

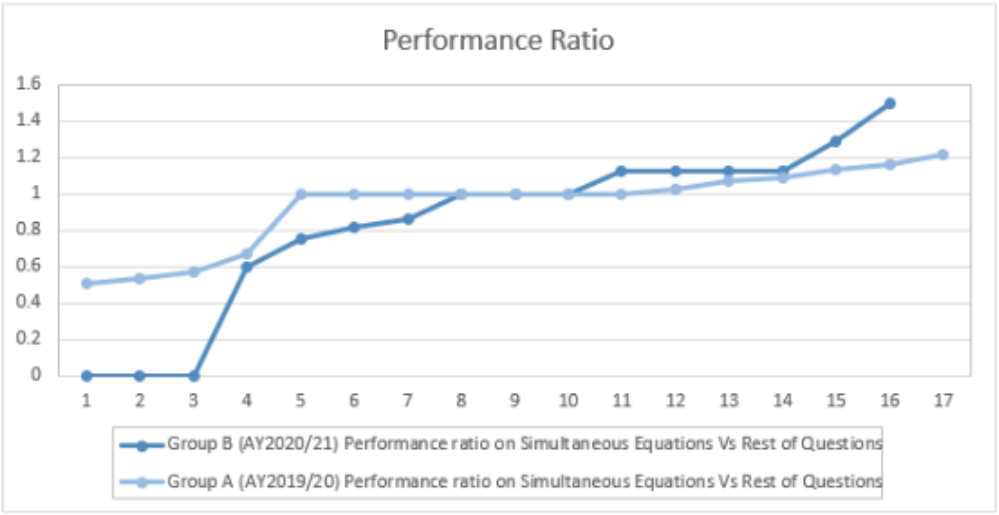

Figure 2. Comparison of the performance ratios for both academic years

Figure 2 shows that the student group that had only face-to-face traditional teaching in the Academic year 2019/2020, had more students with high performance ratio in comparison to the online teaching group of the Academic Year 2020/2021.

(d) Categorical Analysis using binary values

Categorical Analysis is a useful way to deal with categorical data. Categorical variables are those that can be measured using only limited number of variables [(32)]. In this paper a binary logistic categorical analysis is considered.

Table 3: Results of chi-squared test with categorical variable

	Dependent variable:
	Improved1
Online Teaching	−0.009**
	(0.003)
Face-to-face Teaching	0.017***
	(0.005)
Constant	−0.140
	(0.510)
Observations	17
Log Likelihood	−4.677
Akaike Inf. Crit.	15.353
Note:	*p<0.1; **p<0.05; ***p<0.01

The model was constructed by examining if students' results improved or not with the intervention of online teaching. If a student's assessment mark was improved with traditional teaching then it is given a value of "1" but if it did not show any improvement then it was labelled with a "0". The results from the Table 3 shows a negative value for the online teaching for the same module during the pandemic. This value of -0.009 shows that an increase in one unit of the "variable online teaching" reduces the student performance by 0.9% (exp(-0.009) = 0.991) whilst the other factors are kept constant. This outcome suggests that a negative impact of online teaching and learning exists on students' performance.

The "face-to-face variable" has a positive value and this shows that an increase in one unit of the "variable face-to-face teaching" increases the student performance by 1.7% (exp(0.017) =1.017) whilst keeping other factors constant, deducing that face-to-face teaching actually had a positive impact on improvement of results.

3.3 (II) Analysis of results within the same cohort Academic Year 2020/2021

This analysis is performed for the same cohort of students, during the pandemic, where the students were divided into two groups, with one group having only online teaching and other group having a face-to-face delivery for the specific topic of simultaneous equations. A comparison of results of the assessments, summarised in Figure 3, was undertaken in order to distinguish any improvements in marks due to the alternative way of teaching.

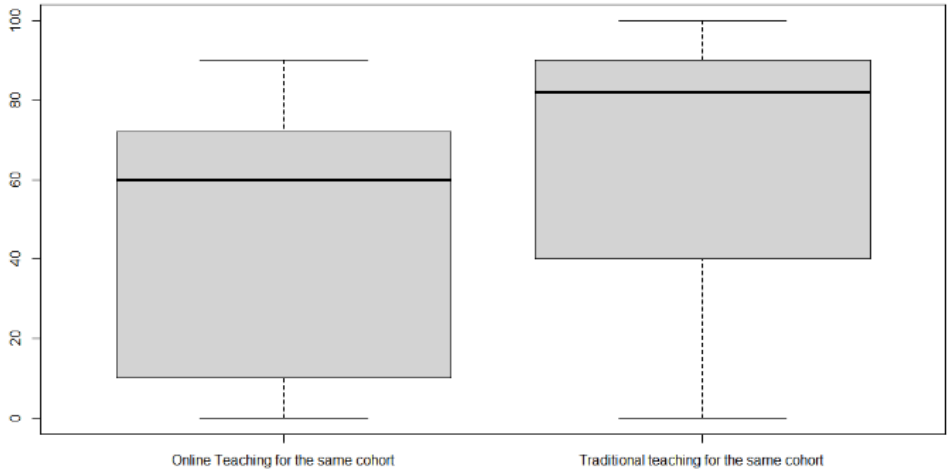

Figure 3. Box plot of the assessment results for Online teaching and Traditional teaching for the same cohort Academic Year 2020/2021

Quantitative Analysis : (a) Chi-Squared test

Table 4 summarises results necessary to perform a chi-squared test. This includes the Likelihood Ratio (LR) and other statistical measures. The null and the alternative hypothesis considered in this section again prove that there is a difference in the mean assessment results of the two teaching methods. The null hypothesis is rejected allowing for the test to be treated significant. The assessment data were collected and the p value obtained, to give 0.0002. This too means that the test is significant, therefore, it can be stated that at 5% level of significance there is enough evidence to reject the null hypothesis meaning that there is a difference in mean assessment of the two teaching methods for the same cohort.

Considering the effect size once more for the data collected within the same cohort, it is found that the effect size is 0.59, allowing for a large effect size under the Cohen's effect size guidelines [(31)]. Hence approximately 73% of the mean of the traditional teaching group fall above the mean of the online group.

Table 4: Results of chi-squared test for the same cohort

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
#Df	2	2.500	0.707	2	2.2	2.8	3
LogLik	2	0.428	4.952	−3.074	−1.323	2.179	3.930
Df	1	−1.000		−1.000	−1.000	−1.000	−1.000
Chisq	1	14.007		14.007	14.007	14.007	14.007
Pr(>Chisq)	1	0.0002		0.0002	0.0002	0.0002	0.0002

(b) Categorical Analysis using binary values

Similar Categorical Analysis can be performed for this section as well. Considering the group where online teaching and face-to-face teaching delivery was conducted to the same cohort of students, an analysis was implemented on whether student performance improved in the face-to-face learning environment comparative to the group that was already experiencing online teaching in Academic Year 2020/2021. The students were given an assessment to fulfill after their learning was delivered on the same topic. All the obtained data were utilised for a categorical analysis. Considering binary values, the results from the face-to-face teaching group was assigned the value '1' and the online group was assigned the value '0'. A binary logistic model was fitted to the data and the output examined. The values represented by the coefficients of the dependent variables, as seen in Table 5, give an interpretation about any improvements on student performance relative to the two teaching methods.

Table 5: Categorical analysis for the same cohort

	Dependent variable:
	Improved1
Online Teaching	−1.441
	(0.841)
Face-to-face Teaching	0.592*
	(0.835)
Constant	0.382
	(0.290)
Observations	9
Log Likelihood	−3.511
Akaike Inf. Crit.	13.022
Note:	*p<0.1; **p<0.05; ***p<0.01

This model under consideration, clearly shows a negative impact on online teaching relative to the face-to-face teaching, with an improved index of 0.592 when taught by the lecturer in the traditional manner. The negative value, -1.441, suggests that keeping other factors constant, an increase in one unit of ”online teaching” actually gives a reduction in improvement by 35.7% (exp(-0.441) = 0.643).

The variable ”face-to-face teaching” suggests that a rise by one unit, improves the student performance by 80.7% (exp(0.592) = 1.807) whilst keeping other factors fixed. This outcome exemplifies that face-to-face teaching has a positive effect on the student experience in relation to online teaching.

Qualitative Analysis: Survey Results Analysis for the same cohort in Academic Year 2020/2021

Questionnaires were adopted and were given to the students as well as to the lecturer who taught the module in the Academic Year 2020/2021. The lecturer was given a questionnaire in order to better understand the mind set of their online teaching. In actual fact, at the start of the pandemic, the academic had to adapt very quickly to the new technological changes and to encompass them in their line of teaching. It was a challenging time for academics and the responses of the questionnaire help to envisage the struggles faced and how they were overcome. The educator also had to adapt to the new environment at home which had an impact on their own family. The time span was very small for the lecturer to come in terms with the new software and applications to conduct classes. The educator also felt the drawback of not seeing the students face-to-face at campus while teaching through the online method, noting a lack of engagement from students with their lecturer and peers.

The response of the lecturer’s questionnaire gave a fruitful insight as to the main drawbacks endured by themselves whilst teaching online, with bad internet connection during live online sessions dominating the encountered problems. The lecturer realised that from the side of the students, there was certainly a lack of engagement and interaction with the educator and amongst peers. On the contrary however, online teaching was beneficial for the students as the recording of lectures gave them the opportunity to watch these sessions many times, so as to gain a better understanding of the topic taught. Moreover, the questionnaire completed by the lecturer allowed for a personal viewpoint to be transferred, that being that online teaching would most probably continue to be used in the higher educational sector, as part of a blended learning approach.

Students’ questionnaire was different it was a search of the explanatory viewpoint of how online learning impacted their learning experience. An insight into the learning hardships faced by the students during the pandemic and which teaching method was preferred by the student was identified. The two figures below, Figure 4 and Figure 5, diagrammatically portray a few of the responses from this student questionnaire.

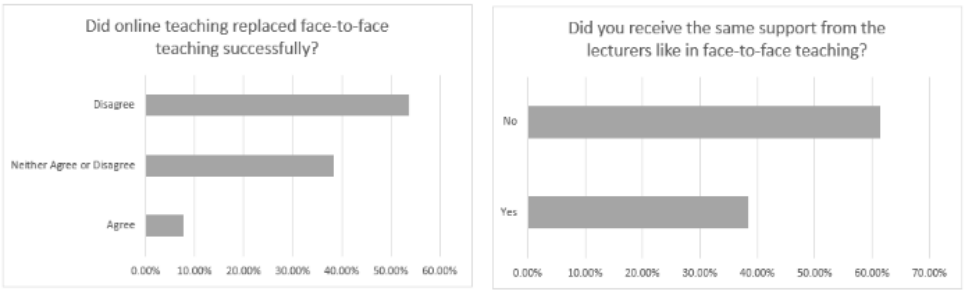

Figure 4. Online teaching vs face-to-face teaching

Figure 5. Preferences of students

In essence, students disagree that online teaching replaced successfully face-to-face teaching, a result that was perhaps anticipated.

4 Conclusions

This paper set out to investigate the effectiveness of student performance for online teaching comparative to the traditional face-to-face teaching for a module called ”Analytical Mathematics” during Covid-19 pandemic.

Many challenges were encountered in teaching during the COVID-19 pandemic. As the move to online learning was unanticipated, both lecturers and students faced difficulties in adjusting to the online teaching experience requiring access to different learning resources through a digital medium. The qualitative analysis of this paper identified and concurred with existing literature the advantages of online learning, one of which being that students had unlimited, anytime access to useful resources such as live or pre-recordings of lectures. Learning was conducted in a more flexible manner which was considered to be more convenient to students as they could listen to lectures and use teaching material at their own preferred time and pace. However, although the learning platforms were a good yet challenging mode to teach, the Academic Year 2020/2021 group that undertook online learning achieved inferior results in the assessments, specifically a reduction in student performance by 35.7%, compared to the group of the same cohort that underwent face-to-face delivery, which showed an improvement in student performance by 80.7%. The immense efforts of the lecturer to engage and interact with students as well as students with their peers also surfaced as a drawback to online learning. Looking through the eyes of the students, 54% agree that they prefer the experience of face-to-face teaching rather than online learning and the majority would not recommend this new online intervention to be used in academia in the future.

To strengthen this inference, a comparison of test results between the two academic year cohorts tackling the different methods of learning was conducted with statistical outcomes supporting and exemplifying that face-to-face learning students did perform more successfully. The results in this paper from the performance ratio, t-test, hypothesis testing, effect size, chi-squared test and categorical variable analysis all confirm the reliability of the study since the results are consistent and the numerical accuracy of the test measures show cast their significance and validity. Notably the Academic Year 2020/2021 that experienced online delivery due to the pandemic on the chapter ”Simultaneous Equations” performed 56.3% better relative to the rest of the questions in the exam, whereas the Academic Year 2019/2020 cohort which endured only traditional face-to-face teaching performed at a higher standard with an analogous percentage of 76.4% . Even if resources of the content material was provided to students online through pre-recordings, links, online discussion forums, students still performed better with face-to-face learning for this STEM related subject.

Current literature has been in favour of online learning concluding its existence as effective in the absence of face-to-face teaching. With the advances in technology, lecturers are able to provide good

quality teaching to students, mirroring the outcomes of the traditional face-to-face method. In order to conduct however effective teaching, educators and students should have the latest form of technology. Even with the cited advantages for this alternative learning approach of online delivery, the question at hand is whether the success of online learning is coherent for all subjects. In other words, how effective is online delivery for subjects in the Science, Technology, Engineering and Mathematics (STEM) sector? It is this research question that lead to the formation of the objective of this paper and to investigate whether during the pandemic, when online teaching was adopted as a necessity, improved students' learning experience and performance compared to the traditional face-to-face delivery method for a STEM related subject.

The conclusive remarks presented in this paper support the negative influence of online learning for students' performance compared to the traditional face-to-face learning technique. The chosen qualitative and quantitative methods embrace the effectiveness of face-to-face teaching compared to online learning for this mathematical module "Analytical Mathematics".

4.1 Suggestions for future research

Future research could consider the following conditions for the online learning experience of students:

- External factor such as students' socioeconomic background; understanding how to support students of a lower socioeconomic background in their engagement of online learning.
  Implementing policies within universities would warrant discussions on providing a good learning experience to all students such as perhaps a laptop to students from lower socioeconomic backgrounds.
- Further analysis for other mathematics modules or STEM related subjects in order to see if these differences in students' learning experience and performance is consistent.
- It would be informative to investigate the impact of online learning amongst a larger cohort and even more so not during a health crisis. It is fair to note that this research study looked at the effects of online learning during Covid-19 pandemic therefore, it is these immediate effects of the transition to online learning that were considered and examined comparative to face-to-face delivery.
- As online teaching also requires good expertise in technology use, that is in organising and delivering content online, it may be important to consider providing training for students and educators with using this type of advanced technology. Consequently, it can be regarded as useful to investigate whether the impact of online learning can be enhanced by training provided to all those involved in the higher education sector.

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Competing Interests

The authors declare no conflict of interest

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