

Analyzing the Impact of Remote Teaching on Calculus I Students' Performance: A Longitudinal Study of Subsequent Calculus Course Success

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Abstract—In this Research Full paper, we investigated the impact of the COVID-19 pandemic on the academic performance of students in the Calculus I course at University of Central Florida. The primary focus of this investigation was to address two pivotal research questions: RQ1: What impact did the COVID-19 pandemic have on students' grade distribution in Calculus I course? RQ2: What impact did the post-COVID-19 pandemic have on students' performance in Calculus II who took Calculus I during the remote teaching period? To provide insights into these inquiries, the study gathered, compared, and analyzed students' grades data from spring 2017 to fall 2021. A similar analysis included the performance of Calculus II students who had completed Calculus I during the remote teaching period. The study was further broken down into three distinct periods based on the teaching modality during the COVID-19 lockdown: before (spring 2017-fall 2019), during (spring 2020- summer 2021), and after (fall 2021) remote teaching period. Results showed that more Calculus I students passed during the remote teaching period, with a considerable increase in the "A" grade rates, and much fewer students failed the course. Despite this promising surge, the overarching trajectory of passing rates reverted to pre-pandemic norms. Furthermore, exploration into the passing rates distribution among Calculus II students, who completed Calculus I during the remote teaching period, varied over the two periods. While there were an increasing percentage of "A" and "B" grades, a significantly increasing percentage of "W" rates was observed subsequent to the remote teaching period. This study holds significant relevance to STEM education as it delves into the effects of the COVID-19 pandemic on student performance in Calculus courses, crucial components of STEM curricula. The findings underscore the critical need to adjust pedagogical methods in order to better engage, support, and empower STEM students on their academic paths.

Index Terms—student data, undergraduate, remote teaching period

I. INTRODUCTION

The coronavirus disease 2019 (COVID-19) is known to have disrupted life across the world. The COVID-19 pandemic has greatly impacted the education sector, specifically during the spring semester of 2020. As the virus spread, many schools and universities were forced to transition from in-person instruction to online teaching [1]. This sudden shift required educators to utilize digital technology and adapt their teaching

methods, including the use of synchronous or asynchronous online instruction and adjustments to assessment activities and criteria [2]– [4].

Since most instructors have never been trained on using online tools, this situation created new challenges for the vast majority of them [5]– [7]. Synchronous online mode focuses on the physical separation of instructor and students but undertakes real-time communication, unlike asynchronous mode [8], [9].

Notably, the remote teaching modality created owing to the emergence of the pandemic must not be conflated with the online learning modality, which is an instructional design and planning, while the remote teaching corresponds to a temporary shift of instructional delivery – ex. face-to-face mode - to remote delivery mode attributed to the pandemic crisis [10]– [12].

Questions were raised about the implications of the COVID-19 pandemic on higher education when the crisis ended which marked the return of teaching to the original format [13]. Against this backdrop, the present paper assessed the ramifications of the COVID-19 pandemic on students' performance in the Calculus I course at University of Central Florida (UCF). More specifically, this study aims to answer the following questions:

RQ1: What impact did the COVID-19 pandemic have on students' grade distribution in Calculus I course?

RQ2: What impact did the post-COVID-19 pandemic have on students' performance in Calculus II who took Calculus I during the remote teaching period?

To tackle these research questions, this study primarily focuses on analyzing the effects of the COVID-19 pandemic solely on students' grades within Calculus courses. The aim is to elucidate the alterations observed in these courses and assess the potential influence of remote teaching on students' academic performance. The findings will be juxtaposed with data from the two preceding academic years and one semester of post-pandemic "normal" instruction for comprehensive comparison.

The paper is divided into six sections: Section II elucidates

the need for improvement in Calculus instruction. Section III provides an overview of the delivery methods for Calculus I and II before, during, and after the pandemic. Data analysis and results are presented in Section IV, followed by a discussion of the main findings in Section V. Finally, Section VI summarizes the key points of the study.

II. THEORETICAL FRAMEWORK

The theoretical framework underpinning this study delves into the intersection of STEM education, particularly mathematics proficiency, and the challenges inherent in Calculus courses, with a focus on the impact of the COVID-19 pandemic.

Firstly, the broader context of STEM education is elucidated, highlighting the significant attrition rates among STEM majors within six years of study, as reported by the President's Council of Advisors on Science and Technology [14]. This attrition is attributed, in part, to deficiencies in mathematical knowledge and skills, a barrier echoed by several researchers [15]– [18].

Central to this discussion is the pivotal role of Calculus in STEM disciplines. Despite its importance, Calculus is often perceived as a deterrent, contributing to high failure rates nationally, as documented by [19]. At UCF, the historical data underscores the prevalence of low success rates in Calculus I, with a DFW rate exceeding 40% in the 2018-2019 academic year.

Moreover, the relationship between success in Calculus I and progression to Calculus II is highlighted. Students must demonstrate proficiency in Calculus I to enroll in Calculus II, a prerequisite that underscores the significance of improving success rates in Calculus I for overall STEM retention [20]– [22].

The transition to remote teaching during the COVID-19 pandemic introduces additional complexities. Although online platforms have reshaped teaching and learning across various disciplines, including mathematics [23]– [24], even before the pandemic, concerns and challenges persisted. For instance, [25] emphasized the importance of balancing lecturer- and student-centered activities in online education, as well as fostering interaction between students, content, instructors, and peers. Additionally, the need for strong technological skills and the lack of face-to-face interaction present further challenges in online teaching compared to traditional, in-person instruction [25]– [26].

Given these research findings, this study aims to analyze the impact of this transition on student performance in both Calculus I and II. By examining grade distribution, passing rates, and performance trends across different teaching modalities, the research seeks to identify any discernible patterns or changes attributable to the pandemic. Insights from this analysis will inform future educational strategies, curriculum development, and support services designed to enhance student success in STEM disciplines, particularly in Calculus courses.

III. METHODOLOGY

A. Research Design

A quantitative research approach was employed to analyze and compare the academic performance of students enrolled in Calculus I and II courses at our university before, during, and after the COVID-19 pandemic. The study aims to utilize statistical data to uncover any significant variations within these specific contexts. According to [27], a quantitative study is appropriate for investigating relationships, differences, and trends using numerical data. The statistical analysis will involve measures such as descriptive statistics and inferential statistics to examine the impact of the pandemic on students' passing rates, grade distributions, and changes in academic performance. By employing a quantitative research design, the study can provide a comprehensive and data-driven analysis of how the pandemic influenced students' academic outcomes in Calculus courses at the university.

B. Course delivery method

At UCF, all classes were forced to transition to remote teaching using video conferencing platforms such as Zoom or Panopto in the middle of spring 2020. Owing to remote teaching, all tests were administered remotely, thus causing major problems for instructors since many of the faculty were never trained to give proctored testing in an online environment. The university provided some minimum training and recommended some online proctoring systems.

The new "normal" face-to-face mode returned in fall 2021 after five semesters of remote teaching during spring, summer, fall 2020, and spring 2021, with summer 2021 having mixed online and face-to-face modes.

In this study, the period during remote teaching refers ranging from spring 2020 to summer 2021, as the "during pandemic period". The "before pandemic period" corresponds to the period preceding remote teaching, spanning from spring 2017 to fall 2019, while the "after pandemic period" pertains to the time following the remote teaching period, specifically during the term of fall 2021.

It is crucial to emphasize that while both instructors and students were impacted by the pandemic in various ways, the rigor of the course remained unaffected in terms of assessments and performance expectations guided by university policies, with the exception of the middle of spring 2020, a period during which instructors and students were acclimating to a new reality. The only aspect that exhibited flexibility during and after the remote teaching period was the policy regarding attendance and make-up assignments.

At UCF, the fall and spring terms span a duration of 16 weeks each, providing ample time for in-depth coursework. Conversely, the summer term is condensed to 12 weeks to accommodate a more compact schedule.

C. Calculus I course description

1) *Description of Calculus I course before the remote teaching period:* The Calculus I course was typically taught

in a large session format of 450 students before the COVID-19 teaching remote. Typically, it entailed the inclusion of an instructor and five graduate teaching assistants (GTAs). The instructor presents two 75-min lectures and the GTAs will deliver the 75 min recitation sessions every week. Each recitation session has about 45 students. The textbook used for the course was Calculus Early Transcendentals by [28]. The syllabus, homework problems, final exams, as well as grading policy, were coordinated for all sections. Although the midterm exams were not identical, they covered the same content and followed a consistent format as specified by the coordinator. Throughout the semester and a comprehensive final exam, three (paper and pencil) midterms were given. Quizzes were given on paper/pencil during the recitation sessions, whereas students completed weekly online homework assignments via the WebAssign platform. The final exam was common and was given on the same day at the same time; and the exam was graded the team of all instructors and GTAs using a rubric. The use of calculators was prohibited during both the tests and quizzes. Instructors used iClickers during lectures for stimulating students' participation as well as for sharing immediate feedback on the students' understanding and attendance. Students' grades were based on a combination of online homework (10%), recitation quiz (10%), clicker questions (5%), 3 midterms (50%) and final exam (25 %).

2) *Description of Calculus I course during the remote teaching period:* All courses were transitioned to remote instruction in second half of the spring of 2020. For the Calculus courses, this was delivered using synchronous Zoom meetings during part of spring, summer, and fall of 2020. In the spring of 2021, instructors had the option to teach in person or continue with the Zoom format. Despite the different teaching modalities, the Calculus courses still had coordinated syllabi, shared online homework assignments, and a consistent grading policy. The course format for the large lecture Calculus I classes remained the same, with one instructor and five GTAs leading large session classes that met twice a week for 75 minutes each, and all recitation sessions were done in Zoom or in person. Zoom meetings and exams required the use of webcams and microphones, and lectures were recorded and posted in a course management system. Four midterms were proctored using an online proctoring service, and the exams were open-note, open-textbook that required students to upload their work. Grading was based on a combination of homework (13%), lecture participation (7%), recitation activities (15%), midterms (50%), a "calculus proficiency check" (5%). Recitation sessions included exercises to reinforce course objectives and occasionally included discussion assignments for peer engagement concerning the course. There were three (paper and pencil) midterms before recitation day and due on recitation day. Additionally, the semester began with a "Calculus Proficiency Check" diagnostic test and ended with a "Calculus Knowledge Check" final exam.

3) *Description of Calculus I course after the remote teaching period:* In the fall of 2021, Calculus I classes returned to in-person instruction. The course format remained the same

as before, with one instructor and five GTAs leading large session classes that met twice a week for 75 minutes each, with 75-min recitations in smaller classes on Fridays. Students had the option to attend the in-person lectures remotely via Zoom. The course included three midterms and a final exam, all administered during recitation sessions. Students were allowed to use a scientific calculator during quizzes and exams, and homework assignments were completed using the Knewton Alta software. Grading was based on a combination of homework (20%), in-class activities (7%), recitation activities (11%), three midterms (36%), quizzes (8%), and the final exam (18%).

D. Calculus II course description

1) *Description of Calculus II course before the remote teaching period:* The Calculus II course was taught in person in a mid-size session format of 50 students before the COVID-19 pandemic. The class met four times a week for 50-minute lectures, led by one instructor. The textbook used for the course was Calculus Early Transcendentals by [29]. Consistency was maintained across all course sections with regards to the syllabus, homework problems, final exams, and grading policy. Although the midterm exams were not identical, they encompassed the same content and followed a consistent format as specified by the coordinator. There were four midterms given throughout the semester and a common final exam, which was graded using a rubric. Students completed weekly online homework assignments through the WebAssign platform, and quizzes were administered on paper during the lecture. Calculators were not permitted during tests and quizzes. Grades were based on a combination of homework (7%), quizzes (8%), four midterms (60%), and the final exam (25%).

2) *Description of Calculus II course during the remote teaching period:* During the remote teaching period, the Calculus II course was delivered using synchronous Zoom meetings (V1 mode). In spring 2021, instructors had the option to teach in person or continue with the Zoom format. The course still had coordinated syllabi, shared online homework assignments, and a consistent grading policy. However, there was no common final exams due to the difficulties in remote proctoring a large group of students. Lectures were recorded and posted in a course management system, along with the instructor's notes. There were four midterms proctored using Honorlock and delivered through a course management system. Exams were open-note and open-textbook, and students were required to upload their work within a limited timeframe. Grading was based on a combination of homework (10%), quizzes (10%), Zoom polling questions (10%), four midterms (50%), and the final exam (20%).

3) *Description of Calculus II course after the remote teaching period:* The course was back to the same format (face-to-face, in-person) as before the pandemic after the remote teaching period, except for the fact that scientific calculators were allowed during quizzes and tests. Additionally, the grading components reverted to the pre-pandemic structure, including

homework (7%), quizzes (8%), four midterms (60%), and the final exam (25%).

IV. RESULTS

The data set used for this study contains all the student grades in Calculus I and II from spring 2017 to fall 2021, including all the spring, summer, and fall semesters. It has 34,216 records and each record has 24 entries. Among the entries, the following information was extracted and used in this study: Calculus I grade, Calculus II grade, which semester the student took Calculus I, which semester the student took Calculus II, and in which institution the student took Calculus I.

To facilitate the research analysis, the +/- grades are grouped as follows: "A" encompasses (A, A-), "B" encompasses (B+, B, B-), "C" encompasses (C+, C, C-), "D" encompasses (NC [No-Credit], D+, D, D-), and "F" remains unchanged. Additionally, the "NCFW" or "DFW" grades are used to denote failure rates, while "ABC" is employed interchangeably to represent passing rates. All assignments were graded on a scale of 100 points. As for the tests, the grading was standardized to a maximum of 100 points, and the distribution followed a predetermined rubric.

A. Research question 1

To answer RQ1, the study compared the grade distribution before, during, and after the remote teaching period. The data collected is about students' performance in Calculus I from spring 2017 to fall 2021 at UCF. The analysis uses descriptive statistics.

Fig. 1 shows the overall students' performance in the Calculus I course. The graph shows that, on average, 65% of students passed the class before the remote teaching period, 90% passed during the remote teaching period, and 69% passed when returning to in-person lectures (fall 2021). The average failure rate decreased by 25 percentage points during the remote teaching period compared to before the remote teaching period but increased by 21 percentage points after remote teaching.

Fig. 2 presents a comparison of the grade average distribution during the remote teaching period and the average marks from the past years' prior remote teaching period. It shows that during the remote teaching period the average "A" rate drastically increased (147%, up from 16% to 40%) and "W" rates considerably decreased (20%, down from 8% to 6%) when compared to prior remote teaching rates. On the other hand, the average "A" rate decreased (down from 40% to 32%) when compared to after-remote teaching rates, and "W" rates went back to the margin of 8% similar to before remote teaching.

According to the results, the teaching remote period did affect the increase in students' grades. A higher number of students passed, with a significant rise in the "A" rates, and fewer students withdrew from the course.

The number of students who received "A" increased by 100% while the overall students' performance passing rates

after teaching remotely (69%) were like prior remote teaching period rates (65% on average). The chi-square test showed a statistically significant difference concerning the distribution of passing rates over the three periods ($p < 0.0001$) in addition to before and after the remote teaching period ($p < 0.0001$).

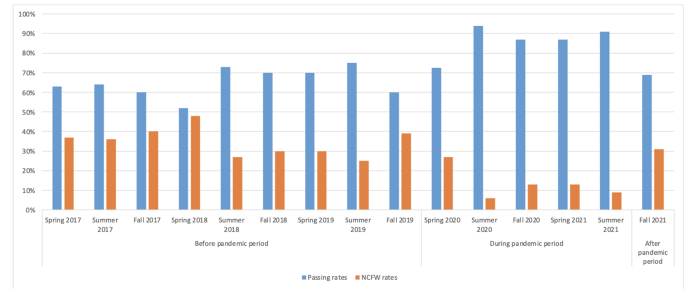


Fig. 1. Overall students' performance of Calculus I course.

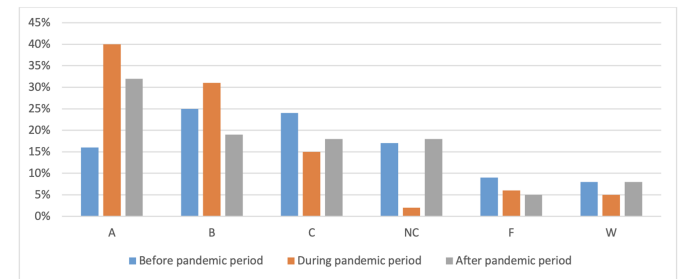


Fig. 2. Comparison of the average grade distribution before/during/after remote teaching period.

B. Research question 2

In order to address RQ3, the grades of UCF Calculus I students in the subsequent Calculus II course (in any semester during the semesters considered in this study) were tracked, and then, the Calculus II grade distribution before, during, as well as after the remote teaching period for students who had passed Calculus I in the preceding semester were compared. The comparison included the letter grade distributions of students who had taken Calculus I either in the prior spring or fall semesters, from spring 2017 to fall 2021. In this analysis, the summer term was not included due to its shorter (12 weeks) duration compared with fall and spring terms (16 weeks).

As shown in Table I, on average, 22.54% and 31.08% of students who passed Calculus I in the fall semester completed Calculus II with "A" and "B" grades respectively in the subsequent spring semester. Conversely, 9.72% and 16.50% of students who passed Calculus I in the spring semester completed Calculus II with "A" and "B" grades respectively in the subsequent fall semester. A reversed pattern holds for DFW grades with more being received by students who passed Calculus I in the spring semester and did not pass Calculus II in the subsequent fall semester.

Another interesting insight from the data can be gleaned: the percentage of students securing an "A" or "B" in Calculus II

TABLE I
LETTER GRADES DISTRIBUTION OF CALCULUS II STUDENTS WHO
COMPLETED CALCULUS I IN THE PRIOR SEMESTER AT UCF

Semester ^a	Grade distribution percentage in Calculus II in the subsequent semester (Spring or Fall)					
	A	B	C	D	F	W
S17	14.53	14.53	30.17	12.85	12.85	15.08
F17	19.46	26.34	30.20	9.40	7.89	6.71
S18	9.60	17.60	29.60	20.80	11.20	11.20
F18	14.35	26.03	24.76	12.78	12.46	9.62
S19	7.91	14.69	27.12	16.38	20.34	13.56
F19	41.11	42.07	12.98	2.88	0.96	0.00
S20	4.72	21.70	30.19	19.81	15.09	8.49
F20	15.24	29.88	22.78	9.17	7.25	15.68
S21	11.83	13.98	16.67	11.83	23.12	22.58

^a Semester of completion for Calculus I at UCF.

witnessed remarkable fluctuations. It surged to 41% and 42% in fall 2019, took a steep dive to 4% and 22% in spring 2020, rebounded to 15% and 30% in fall 2020, and then experienced another drop to 12% and 14% in spring 2021. This trend implies that the rapid shift in instructional practices during spring 2020 might have led to a more lenient grading approach. However, it appears that there was a return to a standardized assessment method across all classes afterward.

Fig. 3 presents a comprehensive overview of the average grade distribution in Calculus II across three distinct phases: before, during, and after the remote teaching period, focusing specifically on students who had completed Calculus I in the previous semester. Notably, the grade distribution after the remote period includes students who took Calculus I in spring 2021 (remotely) and Calculus II in fall 2021 (in person).

On average, 61.38%, 72.05%, and 42.47% of students had passed the Calculus II course before, during, and after the remote teaching period, respectively. It can be seen that there was an increase of "A" and "B" during the remote teaching period. Conversely, there was a concurrent increase in the percentages of "F" and "W" grades among students in Calculus II after the remote teaching period who had previously completed Calculus I remotely.

A chi-square test for association was conducted to determine whether the distribution of the passing rate differs across the three periods and concluded that there was a statistically significant difference ($\chi^2 = 100.77, p < 0.0001$). Notably, the passing rate was indeed higher for the remote teaching period. Moreover, the passing rate was significantly higher before remote teaching in comparison to the after remote teaching period ($\chi^2 = 28.41, p < 0.0001$).

Fig. 4 illustrates the shift in course grades across the grade before and after remote teaching, from a decrease in the proportion of "A", "B", and "C" grades to an increase in fail and withdraw grades in Calculus II students who were awarded an "A" grade in Calculus I in the previous semester. According to a chi-square test, there was a statistically significant difference across the three periods ($\chi^2 = 21.09, p < 0.0003$) in the distribution of grades, as well as between before and after the remote teaching period ($\chi^2 = 24.21, p < 0.0002$).

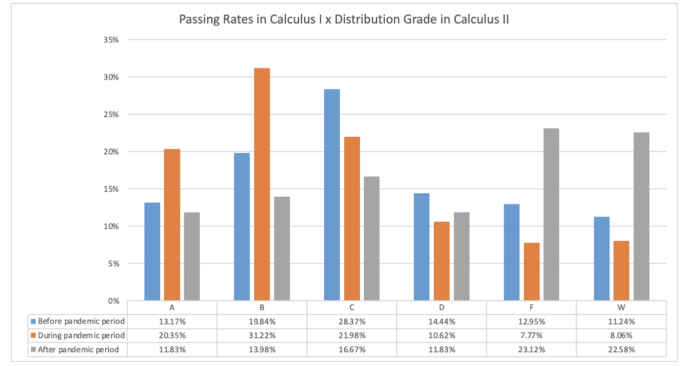


Fig. 3. Comparison of the average grade distribution of Calculus II before/during/after teaching remote period for students who completed Calculus I in the previous semester.

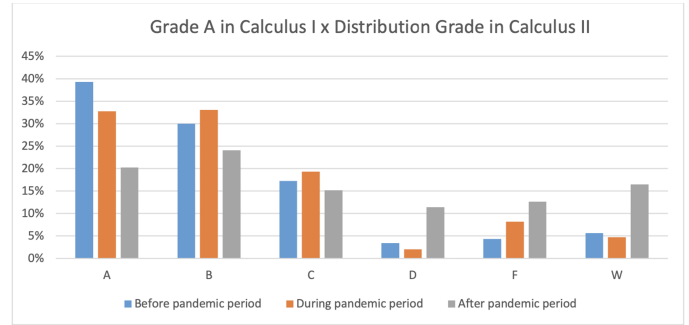


Fig. 4. Comparison of the average grade distribution of Calculus II before/during/after teaching remote period for students who achieved "A" grade in Calculus I the previous semester.

V. DISCUSSION

In the context of addressing RQ1, the analysis reveals the overall academic performance of students during the remote teaching period (the academic year 2020-2021) was significantly better than before the remote teaching period in the Calculus I course. There was an increase in the passing rate, a significant increase in the number of "A" grades, and a decrease in withdrawals. While the overall passing rate for students after remote teaching returned to pre-remote teaching levels, the number of students receiving "A" grades significantly increased after the pandemic. Although there was a considerable increase in passing rates during the remote teaching period, the overall performance of students after remote teaching returned to the trend of pre-remote learning. This suggests that the COVID-19 pandemic did not have a lasting effect on student performance in the Calculus I course before and after the pandemic.

According to [30], the improvement in academic performance may be due to an increase in students' learning strategies and self-regulation skills. Other research suggests that other factors such as organizational, individual (instructors and students), and instructional design elements, particularly the assessment component, may also play a role [31]. In our study, it is also necessary to consider some factors that may have contributed to the increase in students' grades during the

COVID-19 pandemic period. As a case in point, in Calculus I, the tests were taken on an associated platform with randomized questions, while during the remote teaching period, Calculus II students submitted a digitized copy of a hand-written exam on paper. In both instances, students had access to a calculator and notes, which may have favored an increase in grades during that period. Additionally, the possibility of cheating behaviors should be considered, despite efforts by instructors to prevent cheating when designing their exams. Previous research suggests that students perceive cheating to be easier and more prevalent in online courses and that unproctored remote exams may lead to more cheating than proctored ones [32], therefore the potential impact of dishonest behaviors among some students cannot be ruled out.

The results of the analysis of RQ2 show that the overall grade distribution and passing rate of Calculus II students who completed Calculus I in the previous semester at our institution varies across different time periods, with the remote teaching period showing the best results. Additionally, the final grade distribution and passing rates were significantly better before the remote teaching period than after it. There was also a significant increase in "F" and "W" grades after the remote teaching period. The students who received an "A" grade in Calculus I tended to receive more "A" and "B" grades in Calculus II when it was completed before and during pandemic but received more "F" and "W" grades when Calculus II was completed after the remote teaching period. This could be related to various factors such as the transition back to campus with new COVID-19 protocols, emotional stress, and coursework difficulty [33], [18]. Overall, the results suggest a negative impact on the performance of Calculus II students who completed Calculus I during the remote teaching period.

This study has several limitations that must be considered. It focused on only one semester post-pandemic, which may not fully capture long-term trends or the broader impact of returning to in-person learning. Additionally, factors such as student expectations, participation in class, and instructor viewpoints were not analyzed. The potential impact of online exam proctoring and academic integrity, as well as the psychological and emotional challenges faced by students during the pandemic, were also not explored, which could have influenced the observed academic outcomes.

Despite these limitations, the study's goal was to provide an overview of student grade performance across three distinct periods (before, during, and after the pandemic) to identify immediate actions needed to support students. The COVID-19 pandemic has presented an opportunity for educational changes and one of these changes is the instructional and assessment practices [34]. Although this topic is not new, insights into the modifications implemented during the pandemic can provide valuable lessons for enhancing STEM education with technology [35]–[40].

VI. CONCLUSION

Overall, this study examined the impact of the COVID-19 pandemic on students' grades in the Calculus I course at

our institution. The investigation centered on a comparative analysis between the periods of remote teaching and pre-pandemic and post-pandemic in-person instructions, utilizing statistical data to discern any significant variations. While our study did not extend its purview to the realms of student expectations, class engagement, or instructor perspectives, it remained anchored in the objective evaluation of performance standards upheld throughout the three distinct periods.

The findings showed that while student performance in Calculus I course improved during the pandemic period, the overall trend of passing rates returned to pre-pandemic levels. Additionally, variations were found in the distribution of the passing rate among Calculus II students who had completed Calculus I in the previous semester between the two periods. Notably, this analysis identified a substantial increase in failure rates following the phase of remote teaching. This rollercoaster pattern prompts crucial questions: What are the underlying factors contributing to this surge in unfavorable grades? How can we effectively support students who are facing these challenges?

In light of these findings, it is imperative for educators and universities to embark comprehensive reevaluation of what is necessary and beneficial for preparing STEM students for success in the 21st century.

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