Regular Article

Impact of COVID-19 on student performance in a physics laboratory course

Berrin Bilgin [*], Ali Murat Güler

Department of Physics, Middle East Technical University, Ankara, Turkey

A B S T R A C T

This study examines the change in students' performance in a physics laboratory course between distance education and face-to-face education periods before, during, and after the pandemic. It fills a gap in the literature by conducting an in-depth examination of how a transition to distance education affected a laboratory course students' performance using statistical methods.

The results of our study are significant. They show that, in general, students performed better after the pandemic compared to the online period. Students with a CGPA below 2.50 performed at a lower level in the online period compared to the pre-pandemic period, while their CGPAs increased significantly.

Our lives changed significantly when the COVID-19 pandemic began towards the end of 2019. Governments took action to prevent the spread of coronavirus, and one of those was closing schools. Consequently, millions of students' educational lives were profoundly affected. With the closure of schools, remote learning suddenly became the primary mode of education, requiring students and teachers to adapt to this new reality.

In Turkey, with the declaration of the first coronavirus case on March 11, 2023, a series of measures were swiftly implemented to prevent the spread of the virus (CNN TÜRK, 2020). It was decided on March 13 to suspend face-to-face classes at universities across the country temporarily. Remote learning was initiated in universities from March 23 onwards. (Hürriyet Daily News)

At Middle East Technical University, the 2019 fall, 2020 spring, and 2020 fall semesters were conducted remotely, with classes and exams being held online. In the 2021 fall semester, education switched to hybrid education, with theoretical courses mainly delivered online and laboratory classes and exams conducted face-to-face.

However, the pandemic is not the sole factor that brought remote learning to the forefront. Natural disasters can remarkably impact the education system in a country like Turkey, which faces the risk of earthquakes. In this context, the Kahramanmaraş earthquake that occurred on February 6, 2023, remains a current and significant issue. The earthquake damaged many schools, and students faced new challenges adapting to their educational lives. While the wounds of the disaster were being healed, a decision was made nationwide to ensure that students' education would not be interrupted, leading to the transition to remote learning for the 2023 spring semester (Duvar English,

2023). At Middle East Technical University, it was also decided that classes and midterm exams would be conducted online while final exams would be held face-to-face.

The emergence of remote learning during both the pandemic period and the recent earthquake disaster highlights the significance of assessing the effects of this transition on students' academic performance. Since laboratory courses are conducted remotely in situations such as pandemics and natural disasters, and the difficulty of adapting such applied courses to distance education affects students' performance in these courses, examining how students are affected in such conditions is essential.

The literature shows that many studies have been conducted to investigate the effect of the pandemic on student performance. (Binrayes et al., 2022; Borish et al., 2022; Cavanaugh et al., 2022; Díez-Pascual et al., 2022; Dukes III, 2020; Foo et al., 2021; Casalone et al., 2023; Fox et al., 2021; Guo, 2020; Iglesias-Pradas et al., 2021; Inoue et al., 2021; Karadag, 2021; Klein et al., 2021; Nazempour et al., 2022; Smyser, 2022; Velarde et al., 2022). Studies are showing that students' performance is affected both positively and negatively, and there are also results showing that there is no change in performance before and after the pandemic. In one of the studies in Turkey, grades of 152,352 students before the pandemic and grades of 149,936 students after the pandemic were examined. This data includes students from different universities taking different courses. Analysis was conducted by applying correlation, ANOVA, and t-test, and results showed 9.21% grade inflation during the pandemic's remote learning period, which is the highest in the literature (Karadag, 2021). This study also showed that the highest grade inflation was seen in students with the lowest university entrance

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scores. Moreover, a study conducted in Spain focusing on a chemistry laboratory course shows that students' pass rates increased from 70% to 100% in the online teaching period. In addition, the percentage of students with the highest grades increased from 8% to 32% in online teaching during the pandemic (Díez-Pascual et al., 2022). Another study conducted using the data collected from US schools showed a 10% increase in GPAs during the online teaching period (Cavanaugh et al., 2022). Two different studies were conducted using data from students from the School of Telecommunication Engineering and data from dental students, which also showed increased student performance during the online teaching period (Iglesias-Pradas et al., 2021) (Binrayes et al., 2022). However, studies also show that students' performance decreased in online education during the pandemic. In a study in Chicago, grades of around 500 financial engineering course students were statistically examined. Four semesters were included in the research: a disrupted semester by the pandemic, two online semesters during the pandemic, and one face-to-face semester. Students were divided into groups according to their CGPAs (G1=(3.40–4.00), G2=(2.90–3.40), G3=(2.40–2.90), G4=(0–2.40)) and their rank percentage was compared considering different semesters. Kruskal-Wallis test and Mann-Whitney *U* tests were used to conduct the analyses. The main result of this study is that students with a CGPA higher than 2.90 were negatively affected by the transition to remote learning (Nazempour et al., 2022). Similarly, a study conducted at the Li Ka Shing Faculty of Medicine, University of Hong Kong showed that students in face-to-face education group performed better than those in distance learning group. A total of 152 students were examined in this study by comparing their problem-based learning (PBL) performance (Foo et al., 2021). A comparative study between Sweden, Italy, and Turkey also indicated that students' performance was affected negatively by online teaching during the pandemic, and their pass rates decreased (Casalone et al., 2023). Regarding applied classes, a study conducted at Harvard School of Dental Medicine shows that students had higher average faculty scores during the pandemic (Inoue et al., 2021). However, another study where laboratory scores of undergraduate biochemistry students were analyzed showed no significant difference in scores between home-based and on-site learning periods (Velarde et al., 2022). Similar to these two studies and the one conducted in Spain, which was previously mentioned, several studies have analyzed laboratory or practical classes and how students' performance has been affected by the pandemic. In many of these studies, the investigations were based on questionnaires filled out by students and focused on issues such as how satisfied they were with the teaching of laboratory courses or how satisfied they were with different applications implied to laboratory classes, the problems caused by teaching laboratory courses remotely and so on (Borish et al., 2022; Dukes III, 2020; Fox et al., 2021; Guo, 2020; Klein et al., 2021; Smyser, 2022). In addition to the survey results, one of these studies, which focused on teaching physics during COVID-19, showed that scores of students who attended synchronous sessions dropped by 3.5% while scores of those who did not attend dropped by 14.5% (Guo, 2020).

This research study investigates how the performance of modern physics laboratory course students in 3rd and 4th grade changed over different semesters. The Physics Department of Middle East Technical University offers the course to physics and physics education students. Students are from Turkey. The grades of 450 students who took this course over the designated semesters were analyzed. and there are 283 male and 160 female students in total and gender information is missing for 7 students. There are no more demographic data available.

We combined the data from six semesters in pairs: two face-to-face semesters before the pandemic (F2F-BP), two online semesters during the pandemic (ONLINE), and two face-to-face semesters after the pandemic (F2F-AP).

F2F-BP: 2018 fall and 2019 fall semesters.

ONLINE: 2020 spring and 2021 fall semesters.

F2F-AP: 2021 spring and 2022 fall semesters.

Additionally, how students' grades change over the semesters is examined by splitting them into groups according to their CGPAs. The following questions are aimed to be answered.

1. Did distance learning during the pandemic affect students' performance taking the modern physics laboratory course?
2. Is there a significant difference in the student's performance among these three semesters?
3. How did students' performance in different CGPA groups change over these three semesters?

Studies conducted to examine a laboratory course, especially a physics laboratory course, show that the literature is insufficient in terms of investigating how student grades changed in detail before the pandemic, during the pandemic period, and after the pandemic (Díez-Pascual et al., 2022) (Borish et al., 2022; Dukes III, 2020; Fox et al., 2021; Guo, 2020; Klein et al., 2021; Smyser, 2022; Velarde et al., 2022). In this respect, this study is important in evaluating the CGPA of the students of a physics laboratory course together with their exam grades, laboratory grades, attendance, and overall course grades and showing the effects of the pandemic.

The course was taught by the same instructor throughout all semesters. Before and after the pandemic, it consisted of lecture and laboratory classes with six experiments and one bonus experiment. For each experiment, students were evaluated based on two quiz scores before and after the laboratory session, laboratory performance, and a laboratory report. In addition, there was one midterm and one final exam.

During the pandemic, synchronous online classes were conducted to explain experimental setup and data collection. Additionally, videos were provided for each experiment so that students could watch them later. The data collected by lab assistants were sent to students for analysis. Exams and quizzes were given online.

Midterm, laboratory, final, and overall (midterm: 25%, final:35%, laboratory:40%) grades and attendance grades were examined. However, since attendance was not taken in the 2022 fall semester when analyzing attendance grades, F2F-AP was not considered. Only F2F-BP and ONLINE semesters were considered when examining attendance grades. Additionally, midterm and final grades were combined according to their weights (midterm: 25%, final: 35%) to see how written exam grades change throughout the semesters. Students were divided into groups based on their student status to provide a broader perspective on how students' performance changed throughout the semesters. At Middle East Technical University, students with a CGPA below 2.50 are considered unsatisfactory, while those above 2.50 are considered satisfactory. Moreover, students with a CGPA between 3.00 and 3.50 become honor students, while those with a CGPA higher than 3.50 are considered high honor students. So, students were divided into two groups: satisfactory or unsatisfactory student status. Students in Group 1(G1) have a CGPA higher than 2.50, and students in Group 2(G2) have a CGPA below 2.50.

Midterm, final, written exams, laboratory, overall attendance grades, and CGPAs were compared across different semesters. This was done with and without dividing students into two different groups according to their student status. Both descriptive and statistical analyses were performed. Using the grades of each semester, the median and its confidence interval were estimated. Then, different statistical tests were applied to check these results' significance. First, since our data are not distributed as normally, nonparametric tests were used to conduct the analysis: Kruskal Wallis test and Mann Whitney *U* test. Accordingly, the Kruskal Wallis test was used to determine whether there was a significant difference between medians of grades by different semesters. Then, the Mann-Whitney *U* test was applied by grouping the semesters in pairs to determine the semester pairs that indicate a significant difference in grades. These tests are appropriate for evaluating performance across different semesters and educational modalities since they do not require assumptions about data normality and are resistant to outliers. We

excluded the grades of those who did not take the written exams and used the 450 students' grades for analysis.

Moreover, the correlation between attendance and the six parameters mentioned above was also calculated. Python 3.10's seaborn library was used to make plots(Statistical Data Visualization), and IBM SPSS (Version 28) was used to perform analyses.

Two scenarios were defined to examine how students' performance changes over three semesters: the case where students were not divided into groups according to their CGPAs and the case where the students were divided into groups. For the first scenario, each semester's median and confidence interval were calculated. The Kruskal-Wallis test was applied to see whether there was a significant difference between the grades based on these three semesters.

According to the results of the Kruskal-Wallis test, there is a significant difference in final, laboratory, and overall grades between the three semesters ($p < 0.05$). The test results also indicate that there is also a significant difference in CGPA's according to the semesters ($p < 0.001$) (See Table 1, Fig. 1). To detect the significance of these differences between semesters, the Mann-Whitney U test was conducted by comparing semesters in pairs: F2F-BP vs. ONLINE, ONLINE vs. F2F-AP, and F2F-BP vs. F2F-AP.

Mann-Whitney U test results show a significant difference in CGPA's between F2F-BP and ONLINE semesters ($p < 0.001$), indicating that students performed better in the ONLINE period (See Table 1). However, the differences in the midterm, final, laboratory, written exam grades, and overall grades are insignificant.

Comparing ONLINE and F2F-AP periods, the results show that the differences in the final, laboratory, overall grades, and written exam grades are statistically significant ($p < 0.05$) (See Table 1) indicating that students performed better in terms of these in the F2F-AP period.

Comparing two face-to-face semesters before and after the pandemic, the Mann-Whitney U test results show that the change in the performance of students in terms of final, written exam grades, and overall grades are significant with $p < 0.05$, laboratory grades, and CGPAs are significant with $p < 0.001$ meaning that students are performed better in terms of this grades in F2F-AP period compared to F2F-BP period (See Table 1).

Students were divided into two groups to examine how the performances of the students changed between the semesters according to their student status. While the students with satisfactory status were evaluated in the G1(CGPA $\geq$ 2.50) group, the students with unsatisfactory status were evaluated in the G2(CGPA<2.50) group.

To determine whether there was a statistically significant difference between these three periods, the Kruskal-Wallis test was applied. These results showed that all of our parameters except midterm grades showed that the performances differed significantly according to the periods for CGPA group G2. Results for G1 were not significant in terms of each parameter, so the analysis was continued with CGPA group G2 (See Table 2, Fig. 2).

In order to determine in which semesters the difference is statistically significant, the Mann-Whitney U test was applied by grouping the semesters in pairs. Comparing the F2F-BP and ONLINE period, the results showed that the difference in final, laboratory, and overall grades was statistically significant at $p < 0.05$. The difference between CGPA's between these two periods was significant at the $p < 0.001$ level. This indicates that students in G2 performed at a lower level in the ONLINE period compared to the F2F-BP pandemic period, although their CGPAs significantly increased (See Table 2).

The Mann-Whitney U test results of the comparison of ONLINE and F2F-AP periods showed that the difference in final, written exam, laboratory, and overall grades are statistically significant at the $p < 0.001$ level, while the midterm difference is significant at the $p = 0.01$ level. This indicates that students in G2 performed better in F2F-AP compared to the ONLINE period (See Table 2).

The Mann Whitney U test of CGPA group G2 for pre-pandemic and after-pandemic periods showed that the difference in overall grades and CGPAs are statistically significant at $p < 0.05$ level. In comparison, final and written exam grades are statistically significant at $p < 0.01$. This shows that students in G2 performed better in F2F-AP than F2F-BP in terms of final, written exam, and overall grades and their CGPAs increased significantly (See Table 2).

When analyzing attendance grades without dividing the students into CGPA groups, the results of Mann Whitney U test for pre-pandemic and after-pandemic periods in terms of attendance score showed that the difference in medians of attendance scores are statistically significant at $p < 0.01$ level($p = 0.003$). This indicates a significant increase in attendance in the ONLINE period compared to the F2F-BP period (See Fig. 3). Moreover, correlation results with a significance of $p < 0.001$ were calculated. Results indicate a positive correlation between attendance and each parameter in each semester (See Table 3).

When analyzing attendance grades considering different CGPA groups, the results of Mann Whitney U test of CGPA group G2 for pre-pandemic and after-pandemic periods in terms of attendance score showed that the difference in attendance scores are statistically significant at $p < 0.05$ level ($p = 0.034$). This shows a significant increase in attendance in the ONLINE period compared to the F2F-BP period. However, the difference in attendance grades of G1 is not significant. Moreover, correlation results were calculated for G2. Results indicate a positive correlation between attendance and each parameter in each semester. The correlation between attendance and midterm is not significant for F2F-BP. However, correlation is significant for other parameters with $p < 0.001$, while for CGPA, the p-value is .003. In the ONLINE period, correlation results for each parameter are significant at $p < 0.05$ level (See Table 3, Fig. 3).

This study aimed to investigate the effects of remote education on a physics laboratory course students' academic performance. This section discusses research questions introduced at the beginning based on the study's findings. Based on the results, distance learning during the pandemic affects the performance of students taking the physics laboratory course, especially for those with a CGPA below 2.5, and in other specific cases, there are indeed significant differences as well. We also examined how students' performance in different CGPA groups changed over these three semesters. The study results showed that analysis without dividing students into groups according to their CGPA does not

Table 1
Results of Kruskal Wallis and Mann-Whitney U tests.

		Midterm	Final	Laboratory	Overall	Midterm&Final	CGPA
Results of Kruskal-Wallis test.	Kruskal-Wallis H	1.190	11.282	11.456	9.105	5.930	22.873
	df	2	2	2	2	2	2
	Asymp. Sig.	.551	.004	.003	.011	.052	<.001
Results of Mann-Whitney test. (F2F-BP vs. ONLINE)	Mann-Whitney U	8802.500	8739.000	8313.000	8630.500	8955.000	6807.000
	Asymp. Sig.(2-tailed)	.673	.724	.238	.601	.988	<.001
Results of Mann-Whitney test. (ONLINE vs. F2F-AP)	Mann-Whitney U	12586.000	10023.500	11366.000	10681.000	10863.000	12490.000
	Asymp. Sig.(2-tailed)	.528	.002	.038	.022	.038	.166
Results of Mann-Whitney test. (F2F-BP vs. F2F-AP)	Mann-Whitney U	8040.000	6904.500	6581.000	6725.000	7179.000	6813.000
	Asymp. Sig.(2-tailed)	.261	.010	<.001	.004	.035	.001

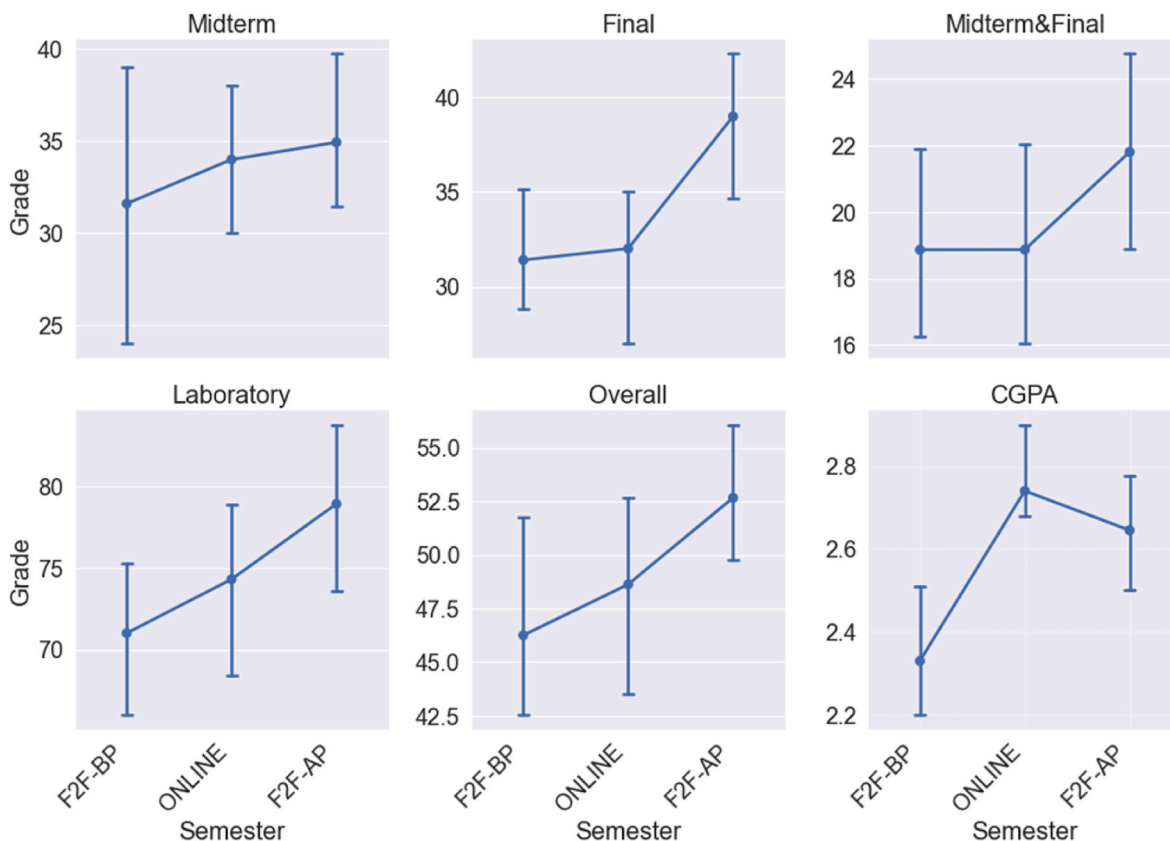*Analysis Without CGPA Groups: Medians of grades through semesters.*

Fig. 1. Analysis Without CGPA Groups: Medians of grades through semesters.

Table 2
Results of Kruskal Wallis and Mann-Whitney U tests.

		Midterm	Final	Laboratory	Overall	Midterm&Final	CGPA
Results of Kruskal-Wallis test for G2.	Kruskal-Wallis H	6.822	24.275	11.737	18.241	19.200	12.400
	df	2	2	2	2	2	2
	Asymp. Sig.	.033	<.001	.003	<.001	<.001	.002
Results of Mann-Whitney U test for G2. (F2F-BP vs. ONLINE)	Mann-Whitney U	1657.000	1366.500	1337.000	1333.500	1420.500	1311.500
	Asymp. Sig.(2-tailed)	.457	.032	.015	.021	.064	<.001
Results of Mann-Whitney U test for G2. (ONLINE vs. F2F-AP)	Mann-Whitney U	1356.500	845.000	1212.000	947.500	942.000	1771.500
	Asymp. Sig.(2-tailed)	.010	<.001	<.001	<.001	<.001	.326
Results of Mann-Whitney U test for G2. (F2F-BP vs. F2F-AP)	Mann-Whitney U	1627.000	1253.000	1785.000	1426.500	1310.000	1818.500
	Asymp. Sig.(2-tailed)	.081	.002	.331	.026	.005	.017

indicate a statistically significant difference in exam grades, except for CGPA, between ONLINE and F2F-BP periods. Therefore, it is not interpretable how students' performance was affected by the transition to remote education during the pandemic in the case of a general analysis.

On the other hand, the result of the analysis by CGPA groups shows us that the performance of students with a CGPA below 2.50 was negatively affected by the transition to remote education during the pandemic in terms of final, laboratory, and overall grades, although their CGPA's increased significantly. Conversely, attendance among these groups increased during the online period. However, this increase may be misleading, as students may have been present in the virtual classroom but not fully engaged. Therefore, further research is necessary to understand these findings better. Examining these students' performance in other courses during the same semesters would be beneficial to gain deeper insights into this phenomenon.

Analyzing the performance changes of the students when education was switched back to face-to-face education after the pandemic, the results indicate significance in general analysis. Analysis results without CGPA groups show that students performed better in exam, laboratory, and overall grades in the F2F-AP period than in the ONLINE period affected by the pandemic. According to the analysis results with CGPA groups, students in G2 (CGPA<2.50) also performed better in exam, laboratory, and overall grades in the F2F-AP period than in the ONLINE period.

Finally, investigating the F2F-BP and F2F-AP periods separated by the pandemic period, the analysis without CGPA groups shows that students' performance increased after the pandemic when they switched to face-to-face education. They performed better in terms of final, overall, and laboratory grades. Their CGPAs also increased significantly. In contrast to this analysis of the CGPA groups, it cannot be said that there is a significant difference in the laboratory grades of the students in the G2 group. However, there is a significant increase in their CGPA and
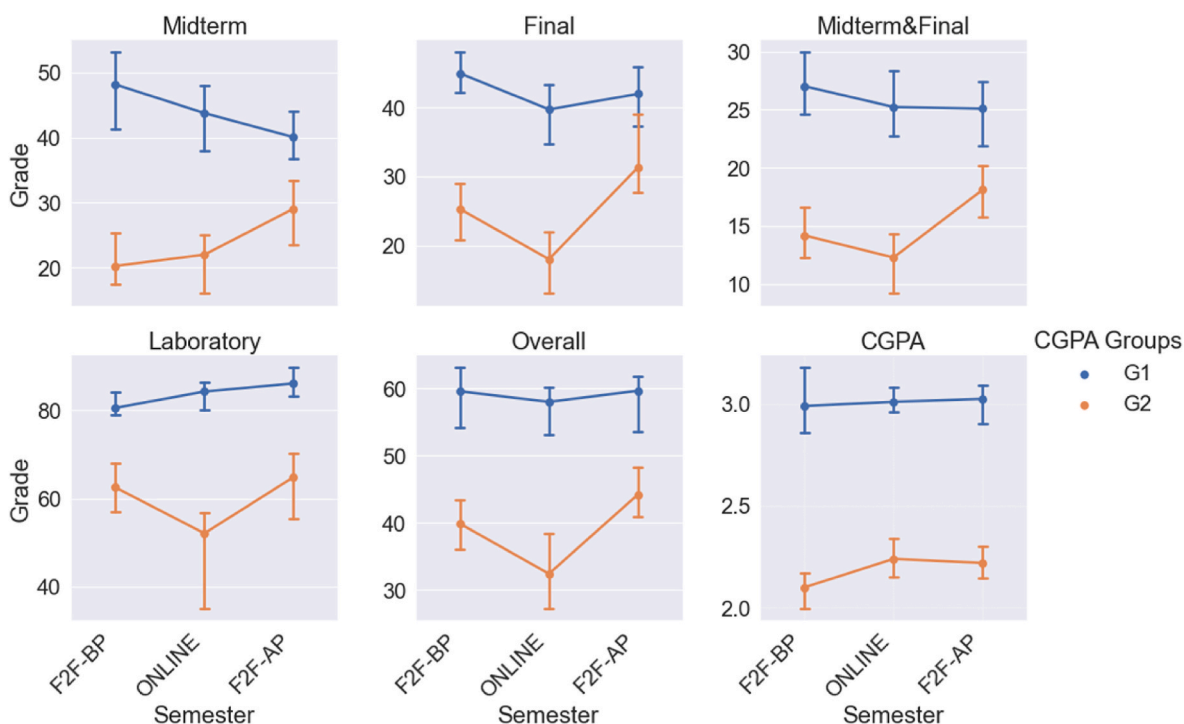
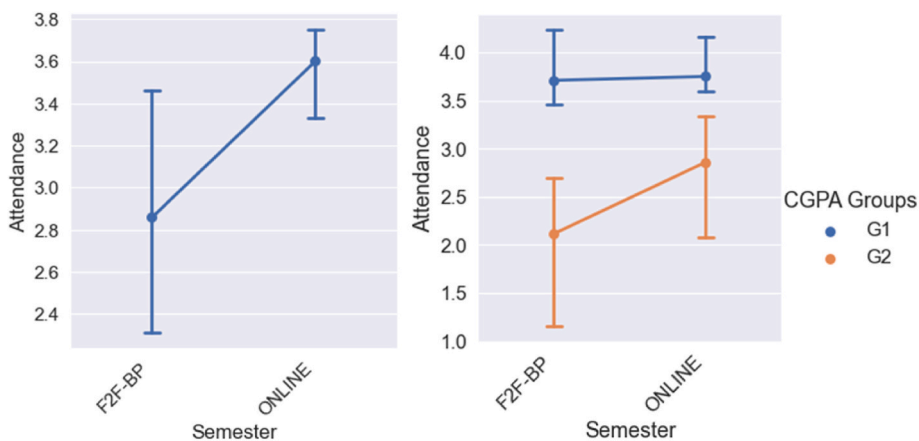**Fig. 2.** Analysis with CGPA groups: Medians of students' grades in different CGPA groups through semesters.

Fig. 3. Medians of attendance according to semesters with and without CGPA groups.

Table 3
Correlation results.

		Midterm	Final	Laboratory	Overall	Midterm&Final	CGPA
G2	Attendance(F2F-BP)	.249	.443	.592	.546	.401	.375
	Attendance(ONLINE)	.352	.332	.654	.566	.382	.273

final and overall grades. In addition to all these analyses, the analysis results of the students in the G1 group, whose CGPA is 2.50 higher, show that their grades are insignificant.

Data availability statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy concerns.

Funding

Ethical approval

This study was conducted to analyze students' exam scores. No personal information of the students was used. We adhered strictly to principles of data privacy and anonymity. The collected data were used solely for the purposes of this study.

CRediT authorship contribution statement

Berrin Bilgin: Writing – original draft, Visualization, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ali Murat Güler:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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