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Online Education and Undergraduates' Academic Record during the COVID-19 Pandemic in China: Evidence from Large-Scale Data

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Abstract: Digital technology-based online education is key to promoting high-quality development of higher education. Many studies have analyzed the effects of online education during the COVID-19 pandemic, but analyses based on large-scale data are lacking. This study uses a quasi-natural experiment during the COVID-19 pandemic to explore the short- and long-term relationships between emergency remote education (teaching and learning) and undergraduates' academic record using multiple comparison analysis of variance (ANOVA) and multiple linear regression. The research data come from the academic record of 123,208 courses of 2622 undergraduates from the classes of 2017–2021 in a Chinese university, across nine semesters. The data do not satisfy the homogeneity of variance hypothesis test; therefore, a non-parametric test is adopted for hypothesis testing. The results show that: (1) In the online education semester, the students' academic record improved substantially with low fluctuation and greater stability; (2) this improvement is more obvious for sophomores and juniors than for freshmen, and (3) online education during the pandemic period significantly improved the course scores of undergraduates, especially sophomores, in the following one or two semesters.

Keywords: online education; undergraduates; academic record; large-scale data; ANOVA

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Citation: Geng, J.; Xun, S.; Yang, J.; Yang, N. Online Education and Undergraduates' Academic Record during the COVID-19 Pandemic in China: Evidence from Large-Scale Data. *Sustainability* **2022**, *14*, 14070. https://doi.org/10.3390/su142114070

Academic Editors: Mohamed Haffar and Fiona Oster

Received: 11 October 2022
Accepted: 26 October 2022
Published: 28 October 2022

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1. Introduction

Because of the COVID-19 pandemic's impact on human health worldwide, people's understanding of knowledge transmission has changed, especially in the field of education. In February 2020, China's Ministry of Education issued guidelines on the organization of online education in colleges and universities, advocating that "classes [are] punctuated, but learning continues." Therefore, colleges and universities across the country launched online education (i.e., online teaching, learning, evaluation, and supervision) activities in the first half of 2020. In the second half of 2020, colleges and universities resumed face-to-face education activities. The pandemic made the majority of teachers, students, and university administrators in China experience a complete "digital technology-based educational experiment," although this "experiment" has the characteristics of an "emergency" situation. During the pandemic, online teaching adopted by Chinese teachers included live teaching, video teaching, and Massive Open Online Courses teaching, with the help of software such as Tencent Conference, Tencent Classroom, Rain Classroom, Super Star Learning, Ding Talk, Tik Tok, and so on.

Previous studies, at home and abroad, have focused on online education from different perspectives. First, researchers have studied the influential factors of students' online learning, finding that parent participation [1,2]; teacher–student interaction [3,4]; and students' autonomy [5,6], learning engagement [7,8], and learning preference [9,10] are important factors affecting students' online learning outcomes. Second, scholars measured students' online learning participation from three aspects: pre-class self-study, classroom activities, and after-class activities [11], which specifically included online discussion,

video-watching, number of visits, learning duration, knowledge point test, chapter assignment, and goal achievement [12,13]. Third, researchers evaluated the effect of online teaching from different aspects of curriculum construction (including curriculum contents, teaching plans, and skills) [14,15], teacher–student growth (including student ability, achievement, and teacher–student satisfaction) [16,17], and organizational support of colleges and departments (including organizational endowment, network environment, and technical support) [18,19].

Recently, numerous domestic and foreign researchers have studied emergency remote teaching and learning during the COVID-19 pandemic, comparing different effects of online and offline education on students' learning outcomes albeit with inconsistent conclusions. Some scholars claimed that online education is better because students' performance, ability, and course score improved after online learning [20], showing high levels of learning initiative, homework completion [21,22], and positive evaluations [23,24]. Others showed that online teaching was not as effective as classroom teaching in improving students' performance and outcomes [25]. Students' learning and the persistence effect was poor [26], and teachers' and students' satisfaction were low [27], because it was difficult to receive timely feedback [28,29]. Online education was only suitable for students with time management skills and strong self-regulation ability [16]. In addition, other scholars argued that there was no significant difference in the impact of online and offline education on students' learning performance [30,31]. That is, the effect of online education was substantially equivalent to that of offline education [32], and the overall feelings of different students toward online learning greatly differed, leading to huge variances in the effect of online education [33,34].

In general, the literature discussed above serves as a reference to evaluate comprehensively the effect of online education. However, these studies have the following shortcomings: (1) The vast majority of research data were obtained through questionnaires. Even the data of students' scores were also self-reported, making them highly subjective; (2) the survey data were all one-off surveys, lacking opportunities for horizontal and vertical comparative analysis; and (3) few studies have adopted an experimental approach, and the research samples were very small (no more than 100 people) and limited to certain courses or teaching methods. Therefore, an objective evaluation—of the impact of online education on students' learning outcomes through large-scale data and long-term analysis—is urgently needed.

Accordingly, this study's objective is to provide empirical evidence and data support for an objective observation and evaluation of the emergency remote teaching and learning effects during the COVID-19 pandemic. This study contributes mainly in the following aspects: (1) The pandemic has created a quasi-experiment of emergency online education in China. Different data from the early, current, and later stages of this quasi-experiment were collected, through which the impact of emergency remote teaching and learning on students' learning outcomes for different grades and semesters can be detected; and (2) the data used in this study were large-scale panel data, which came from 2622 undergraduates and 123,208 courses across nine semesters in a Chinese university. To some extent, this might close the gap in the lack of data objectivity from the self-reported surveys used in previous studies.

2. Materials and Methods

2.1. Population and Sampling

The undergraduates whose grades were examined in the quasi-natural experiment came from a Chinese university. The university, located in a prefecture-level city of Anhui Province, is a key university with more than 29,000 full-time undergraduates. The School of Economics and Management, an independent secondary unit, was selected as the cluster sample of participants in this study. This school has more than 2000 full-time (four-year) undergraduate students, pursuing eight types of majors. Table 1 lists the distribution of all types of majors and the number of students for which the study data correspond.

Table 1. Major type and population distribution of the research data.

Specialty	Class of 2017 [2]	Class of 2018 [2]	Class of 2019 [2]	Class of 2020	Class of 2021	Total
Finance and banking	80	89	85	101	120	475
E-commerce	68	70	62	61	79	340
Human resources management	74	70	79	70	79	372
Marketing	68	61	54	50	74	307
Environmental economics	34	32	31	35	39	171
Management information system	37	32	35	35	40	179
Financial management	94	78	79	86	82	419
Accounting [1]	-	81	73	86	119	359
Total	455	513	498	524	632	2622

[1] In 2018, the school started recruiting students majoring in accounting. [2] Students from the classes of 2017–2019 fully participated in online courses for one semester during the pandemic.

Before the outbreak of COVID-19, most of the courses were delivered through face-to-face communication. During the pandemic, universities launched online teaching activities in the first half of 2020 (i.e., the second semester of school year 2019–2020). In the second half of 2020, teachers and students returned to the campus and resumed classroom teaching and learning activities. Therefore, the subjects involved in this quasi-natural experiment included undergraduate students from the classes of 2016–2019.

Considering that the undergraduates from the class of 2016 were in the off-campus internship stage in the second semester of their senior year during the COVID-19 pandemic, there were no online courses in the semester; hence, they were not suitable for the experiment, and their data were removed from the study accordingly. In addition, to evaluate whether online education had an impact on the students' follow-up offline learning outcomes, we added the data of two classes of 2020 and 2021 as the control group for comparison. Finally, the subjects of this study were all full-time undergraduate students from 2017 to 2021—a total of 2622 students.

2.2. Grouping

Among all the samples, students from the classes of 2017–2019 were the ones who participated in online education in this quasi-experiment. Their course scores in the second semester of 2019–2020 were used as the experimental data, and their course scores for the remaining semesters were used as the control data for the within-subjects comparison. The course scores of undergraduates of the classes of 2020–2021 were used as the control data for the between-subjects design for comparison. Notably, the students' courses and related teachers remained almost unchanged between 2017 and 2021. Through within- and between-subjects comparisons, we can fully evaluate students' learning outcomes by grade and by semester, as influenced by the online education during the pandemic period.

2.3. Data Sources and Analysis

Authentic and objective data, derived from the undergraduate educational administration system, comprised a total of 189,903 grades. We selected the relevant grades data as follows. First, the data of all physical education courses were deleted. Second, all courses must have direct or indirect participation and interaction of teachers, and students' course scores must also be given by teachers. Therefore, some online courses related to extra-curricular reading (e.g., Wisdom Tree and Erya online courses) that are automatically scored by the computer system were removed. Finally, we deleted the data of a small number of students who changed majors. Similarly, data on individuals who returned to school and retook the courses after joining the army were also removed. Finally, we selected 123,208 pieces of data applicable to this study, covering the final scores in 434 courses of students from eight undergraduate specialties across nine semesters from 2017 to 2021. The courses included general curriculum, public foundation curriculum, public elective curriculum, basic subject curriculum, professional curriculum (including core courses, compulsory courses, elective courses, course design, and graduation project), and so on.

ANOVA, multiple comparison tests, and multiple linear regression were conducted in this study, and the data were processed and analyzed by SPSS27.0 software.

3. Results

3.1. Comparison of Scores by Semester

In the first and second semesters of 2017–2018, the data only contained those of students of the class of 2017. In the first semester of 2018–2019, students of the class of 2018 were enrolled at the university. In the first semester of 2019–2020, students of the class of 2019 were enrolled. In the first semester of 2020–2021, students of the class of 2020 were enrolled. In the first semester of 2021–2022, students of the class of 2021 were enrolled, and students of the class of 2017 were graduated. The annual enrollment of the college showed an increasing trend (see Table 1 for details). Therefore, the sample size in Table 2 gradually increases from top to bottom every semester. In this study, the experimental group samples affected by the pandemic were from the second semester of 2019–2020 (shown in bold in Table 2). A comparison of the mean scores of students in different semesters shows that the course scores of students who adopted online learning during the pandemic were significantly improved compared with their scores in the four semesters before the pandemic, but lower than those in the three semesters after the pandemic. The small standard deviation and standard error of the data indicate that online education better promotes the stability of students' academic record.

Table 2. Data grouping by semester (N = 123,208).

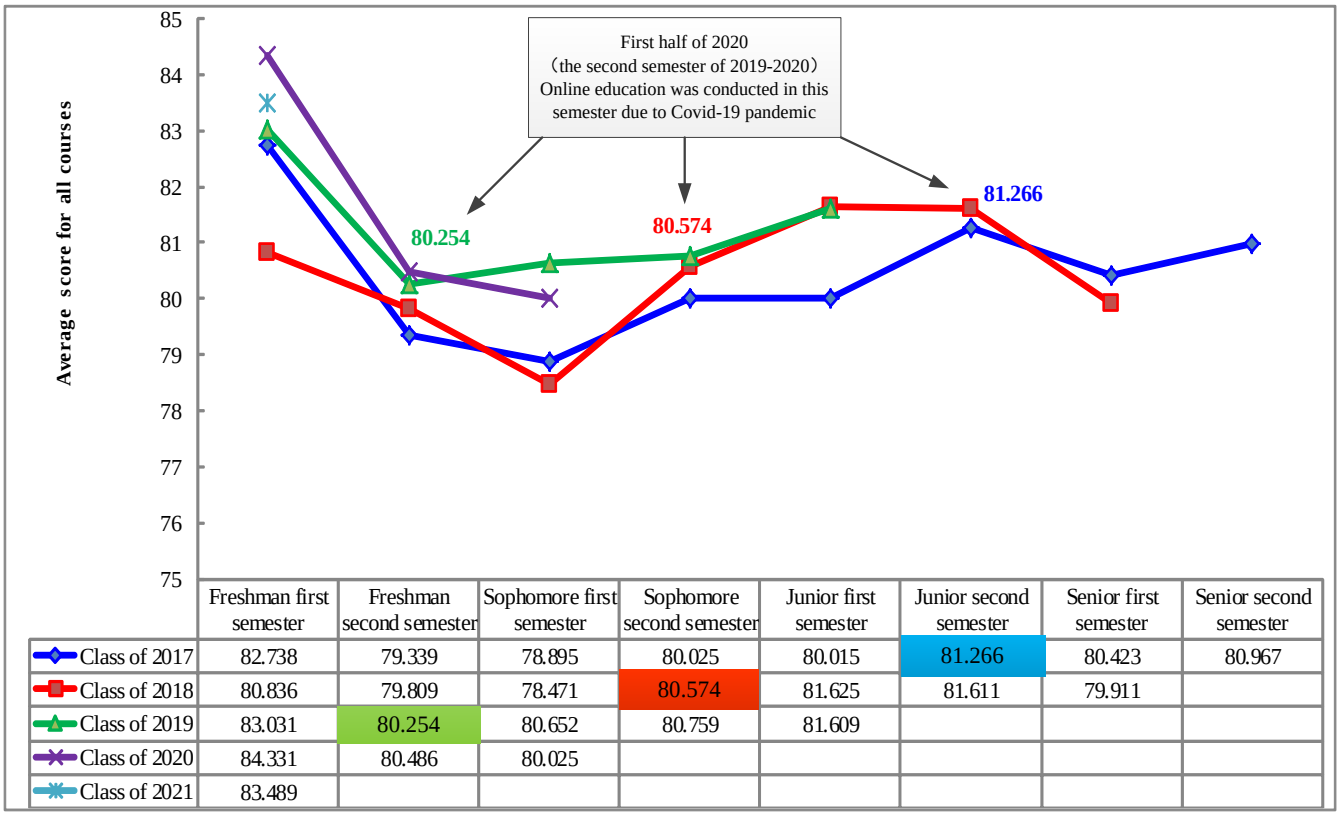
Semester	Sample	Mean [2]	Standard Deviation	Standard Error of Mean	Skewness	Kurtosis	Confidence Interval	
							Up Limit	Down Limit
First semester of 2017–2018	4865	82.738	9.953	0.143	−1.151	2.965	82.458	83.018
Second semester of 2017–2018	4723	79.339	11.952	0.174	−1.641	5.489	78.798	79.480
First semester of 2018–2019	10,555	79.556	11.067	0.108	−1.257	4.522	79.345	79.767
Second semester of 2018–2019	10,588	80.153	10.956	0.106	−1.613	7.212	79.944	80.361
First semester of 2019–2020	16,751	80.250	10.973	0.085	−1.457	5.852	80.083	80.416
Second semester of 2019–2020 [1]	17,166	80.915	9.585	0.071	−1.376	6.258	80.771	81.058
First semester of 2020–2021	18,714	82.002	9.708	0.073	−1.299	5.185	81.863	82.161
Second semester of 2020–2021	19,302	80.976	10.283	0.074	−1.258	4.766	80.727	81.118
First semester of 2021–2022	20,544	81.689	10.482	0.073	−1.163	3.320	81.539	81.826
Sum	123,208	80.905	10.458	0.030	−1.358	5.243	80.847	80.963

All the data correspond to students of classes 2017–2021, excluding students from 2016 and before. [1] The COVID-19 outbreak was in January 2020, and online education was adopted only in this semester. [2] The highest mark is 100.

3.2. Comparison of Scores by Classes

Considering that online education was delivered to freshmen, sophomores, and juniors during the pandemic period, we classified and sorted out the data to observe and compare more clearly the differences in online learning effects among students of different grades. The academic record curves of students of the classes of 2017–2021 in different periods of the four years covered in this study are drawn in Figure 1. The score data of students in the same class and different semesters (row data in Figure 1) allow a self-longitudinal comparison of students' scores (within-subject design). Meanwhile, the score data of students of different classes in the same semester allow a horizontal comparison of students' learning outcomes (between-subject design). First, students of the classes of 2020 and 2021 were not enrolled during the pandemic period, and their academic record data can be used as control data for comparative analysis. The analysis shows that students' course scores in the first semester of their freshman year were higher, and the same phenomenon is observed on the grade curve of students of the class of 2017–2019. This may be due to the fact that freshmen students, when they first entered the university, still maintained the learning attitude and habits of their high school years, and this enabled them to perform better given that self-study activity in the evening was required among freshmen. Students' scores began

to decline significantly in the second semester, and then fluctuated up and down among students of the classes of 2017–2021.



	Freshman first semester	Freshman second semester	Sophomore first semester	Sophomore second semester	Junior first semester	Junior second semester	Senior first semester	Senior second semester
Class of 2017	82.738	79.339	78.895	80.025	80.015	81.266	80.423	80.967
Class of 2018	80.836	79.809	78.471	80.574	81.625	81.611	79.911	
Class of 2019	83.031	80.254	80.652	80.759	81.609			
Class of 2020	84.331	80.486	80.025					
Class of 2021	83.489							

Figure 1. Average academic record of undergraduate students in each semester from 2017 to 2021.

During the online learning period in the second semester of 2019–2020, students of the class of 2019 were in the second semester of their freshman year (green curve in Figure 1). Online education did not change the trend that the academic performance (average score of 80.254) declines in the second semester. However, in the following three semesters, there was a small and stable improvement in their academic record, and this phenomenon also appeared in the class of 2018. In the second semester of their sophomore year (red curve in Figure 1), students of the class of 2019 had significantly increased their academic record (average score of 80.574) compared with their scores in the previous two semesters (the second semester of their freshman year and the first semester of their sophomore year). Their academic record improved further in the following two semesters (the first and second semesters of their junior year), but began to decline in the beginning of their senior year. Students of the class of 2017 experienced all eight semesters of the study period, from their freshman year to graduation. They were in the second semester of their junior year when they started online learning (blue curve in Figure 1). Online education contributed to their academic record for this semester becoming the second highest (average score of 81.266), only lower than that of their freshman year in the first semester. However, in the first semester of their senior year, a drop is still observed. The data of senior students had no value for comparison because they had no other courses except for off-campus internship and graduation thesis.

3.3. Multiple Comparison Tests

The analysis above is only based on the descriptive statistical results of the data, without conducting a strict significance test. To obtain a more scientific and accurate conclusion, we conducted multi between-group comparison ANOVA test on the data by semester and by class. ANOVA is a prevalent statistical method used widely in educational

and psychological research. Before conducting an ANOVA test, an important first step is to verify the distributional assumptions. We used the Levene's and Shapiro–Wilks tests to examine normality and heterogeneity of variance, respectively [35]. The data present a skewed distribution and do not satisfy the homogeneity of variance hypothesis test, meaning that a non-parametric test was required. Considering the group size and asymmetry of samples in different groups, the Kruskal–Wallis rank sum test was used for multiple between-group comparisons in the ANOVA test. Because there was too much information from the multiple comparison test results, we dichotomized the results from inferential statistics into significant or non-significant ones and summarized them in Table 3. The details of the test results are listed in Tables A1 and A2 in Appendix A. We combined these results with the data in Figure 1 and conducted the following analysis.

Table 3. Significance test of academic record grouping by semester and grade.

Semester		First Semester of 2017–2018	Second Semester of 2017–2018	First Semester of 2018–2019	Second Semester of 2018–2019	First Semester of 2019–2020	Second Semester of 2019–2020 [1]	First Semester of 2020–2021	Second Semester of 2020–2021	First Semester of 2021–2022
Grouping		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Inter-group comparison of student academic record by semester										
Significant		2,3,4,5, 6,7,8,9	1,4,5, 6,7,8,9	1,4,5, 6,7,8,9	1,2,3, 7,8,9	1,2,3, 7,8,9	1,2,3, 7,8,9	1,2,3, 4,5,7,8	1,2,3, 4,5,6,7,9	1,2,3, 4,5,6,8
Not significant		-	3	2	5,6	4,6	4,5	9	-	7
Inter-group comparison of student academic record by semester and grade										
Class of 2017	Significant	2,3,4,5, 6,7,8	1,3,4, 5,6,8	1,2,4, 5,6,8	1,2,3, 7	1,2,3, 6,7	1,2,3, 5,7	1,4,5, 6,8	1,2,3, 7	N/A
	Not significant	-	7	7	5,6,8	4,8	4,8	2,3	4,5,6	N/A
Class of 2018	Significant	N/A	N/A	4,5,7, 8,9	3,5,7, 8	3,4,6, 7,8,9	5,7,8	3,4,5, 6,8,9	3,4,5, 6,7,9	3,5, 7,8
	Not significant	N/A	N/A	6	6,9	-	3,4,9	-	-	4,6
Class of 2019	Significant	N/A	N/A	N/A	N/A	6,7,8, 9	5,9	5,9	5,9	5,6,7,8
	Not significant	N/A	N/A	N/A	N/A	-	7,8	6,8	6,7	-
Class of 2020	Significant	N/A	N/A	N/A	N/A	N/A	N/A	8,9	7	7
	Not significant	N/A	N/A	N/A	N/A	N/A	N/A	-	9	8

[1] COVID-19's outbreak was in January 2020, and online education was adopted only in this semester. The numbers (1–9) of the between-group difference comparison represent different semesters. N/A means no data. The Kruskal–Wallis rank sum test was used for multiple between-group comparisons, and the significance values were adjusted by Bonferroni correction method. Significant means of students' academic record in this group (semester) differed from those of other groups (semesters) at the $p = 0.001$ level. Not significant means of students' academic record in this group (semester) did not differ from other groups (semesters) at the $p = 0.05$ level.

Table 3 was divided into two parts. In the first half, students' scores were compared between groups by semester. The results show no significant difference in students' academic scores in the second semester of 2019–2020 (marked as the sixth semester) compared with those in the previous two semesters (marked as the fourth and fifth semesters). Although the average value of students' scores in Table 1 had increased, the online teaching activities carried out during the pandemic had not significantly improved students' academic record. However, in the seventh and eighth semesters after the pandemic, students' academic performance significantly improved compared with their performance in the sixth semester, suggesting that online education during the pandemic had a delayed effect on the improvement of students' learning outcomes after the pandemic.

There may be differences in the online learning outcomes of students from different grades, resulting in the total data being leveled, which may lead to the total data failing to pass the significance test. Therefore, the lower part of Table 3 compared the students' scores by semester and grade between groups. The data for the class of 2021 were only available for one semester; thus, a comparative analysis between semesters was not possible.

There were three semesters of data for students of the class of 2020 showing that there was no significant difference in students' academic performance between the second

semester of 2020–2021 (the second semester of their freshman year, marked as the eighth semester in Table 3) and the first semester of 2021–2022 (the first semester of their sophomore year, marked as the ninth semester in Table 3). This data comparison demonstrates no significant difference in the course data of students who did not experience online learning during the pandemic period (the control group) in the two semesters after the pandemic.

There were five semesters of data for students of the class of 2019, who are the ones that participated in online learning in the second semester of their freshman year. The data in Table 3 show no significant difference in students' learning outcomes between the sixth semester during the pandemic and the seventh and eighth semesters after the pandemic. Notably, the data comparison between the seventh and fifth semesters was useless, as we have previously emphasized that the fifth semester is the first semester of the freshman year for students of the class of 2019, and the academic record is generally higher than for any other semester.

For students of the class of 2018, there was a significant difference between their academic record for the sixth semester during the pandemic and the fifth semester before the pandemic, as well as the seventh and eighth semesters after the pandemic. The results further show that their academic record for the sixth semester was significantly higher than that for the fifth semester and significantly lower than that for the seventh and eighth semesters. Combined with the analysis above of the class of 2020 students (control group), the results strongly suggest that students in the second semester of their sophomore year during the pandemic had significantly improved their academic performance when they adopted online learning. In addition, we found a lag effect of online education in that the students' face-to-face learning performance in the following two semesters improved substantially.

For students of the class of 2017, their academic record for the sixth semester during the pandemic also shows a significant improvement compared with their academic record for the fifth semester before the pandemic. This result further supports the finding that online education improved students' learning performance and outcomes. It should be stressed here that although their academic record decreased in the seventh and eighth semesters after the pandemic ended, this should not be used as evidence to reject the abovementioned lag effect because students of the class of 2017 were already in their senior year and had fewer courses in the seventh and eighth semesters.

In conclusion, the current effect of online education during the pandemic on students' academic record was verified in the data of sophomore and junior students from the classes of 2017 and 2018, while the lag effect was only verified in the data of sophomore students from the classes of 2018.

3.4. Multiple Linear Regressions

To obtain further scientific support for the study's results, logarithmic transformation was applied to normalize the data, and multiple linear regression analysis was conducted. The dependent variable of the regression equation is the continuous course score, and the independent variables are the dummy variables of different semesters. The regression results of using dummy variables are summarized in Table 4.

The linear regression results in Table 4 are similar to those of the ANOVA in Table 3, which further support the reliability of this study's findings. The regression analysis of all the data indicates that online education during the pandemic period significantly improved the course scores of all the students in the sixth and seventh semesters. The regression analysis of grade (class) data also shows that online education during the pandemic period significantly improved the course scores of junior students in the sixth and seventh semesters and improved the course scores of sophomores in the seventh and eighth semesters.

Table 4. Multiple linear regression results of dummy variables.

		Non-Standardized Coefficient		Standardized Coefficient	*t*	*p*	*F*
		B	**Standard Error**	**Beta**			
All classes	Constant	80.715	0.08		1014.944	0.000	114.048 (0.000)
	1	2.023	0.169	0.038	11.956	0.000	
	2	−1.576	0.171	−0.029	−9.206	0.000	
	3	−1.159	0.129	−0.031	−8.991	0.000	
	4	−0.562	0.129	−0.015	−4.366	0.000	
	5	−0.465	0.113	−0.015	−4.112	0.000	
	7	1.287	0.11	0.044	11.686	0.000	
	8	0.158	0.109	0.005	1.442	0.149	
	9	0.968	0.108	0.035	8.984	0.000	
Class of 2017	Constant	81.266	0.144		564.918	0.000	74.412 (0.000)
	1	1.472	0.212	0.047	6.939	0.000	
	2	−2.127	0.214	−0.067	−9.947	0.000	
	3	−2.771	0.203	−0.094	−13.654	0.000	
	4	−1.151	0.209	−0.034	−5.596	0.000	
	5	−1.271	0.202	−0.04	−5.803	0.000	
	7	−1.843	0.305	−0.036	−6.046	0.000	
	8	−0.299	0.37	−0.005	−0.809	0.419	
Class of 2018	Constant	80.573	0.125		644.608	0.000	90.762 (0.000)
	3	0.262	0.193	0.008	1.356	0.175	
	4	−0.764	0.186	−0.026	−4.099	0.000	
	5	−2.202	0.179	−0.079	−12.279	0.000	
	7	1.738	0.177	0.060	9.622	0.000	
	8	1.651	0.174	0.028	9.233	0.000	
	9	−0.663	0.257	−0.014	−2.583	0.010	
Class of 2019	Constant	80.254	0.145		554.353	0.000	63.523 (0.000)
	5	2.777	0.207	0.102	13.397	0.000	
	7	0.297	0.196	0.012	1.515	0.130	
	8	0.304	0.193	0.013	1.573	0.116	
	9	1.355	0.192	0.057	7.071	0.000	

Notes: 1 = first semester of the academic year 2017–2018; 2 = second semester, 2017–2018; 3 = first semester, 2018–2019; 4 = second semester, 2018–2019; 5 = first semester, 2019–2020; 7 = first semester, 2020–2021; 8 = second semester, 2020–2021; and 9 = first semester, 2021–2022. The reference group is 6 (second semester of 2019–2020).

4. Discussion

The findings that online education helped improve students' learning performance and outcomes has been supported by many studies [20,21]. We found this improvement to be especially true for upper-level students. A recent survey of Chinese college students showed that juniors and seniors had better online learning skills than freshmen [36]. Another study from China found that lower-grade undergraduates prefer to be taught in the classroom [22]. The reasons might be the higher requirements of online education with respect to students' basic quality, skills, and abilities compared with the requirements of traditional classroom education. Specifically, upper-level students were found to be more proficient in computer technology, more well-rounded in their learning ability, and show higher learning autonomy and stronger independent thinking. They could obtain, screen, and sort out abundant information on the Internet to facilitate online learning, such that their online learning performance was better. By contrast, the skill and ability of freshmen were relatively weaker, and their online learning performances were relatively lower than those of upper-level students.

This study has another finding that online education could significantly improve junior students' offline academic record in the following one to two semesters. The experimental research of Welsh scholars showed no significant difference in student performance between the online learning and classroom lecture groups and that in contrast to our

findings, the subjects in the classroom lecture group performed better (with more cases reported). However, the course scores of students in the classroom lecture group decreased significantly after two weeks, while those in the online learning group did not show such a decline [37]. In another study, Dutch scholars conducted a controlled intervention experiment on 71 fourth grade medical students of Duke University, finding that online learning within a limited time significantly improved the clinical practice performance of medical students after six months [38]. This previous study supports the conclusion of our study to a certain extent, that is, online education has a lag effect on the improvement of undergraduates' learning performance. The reason may be that online education can better cultivate students' information literacy [39], improve students' autonomous learning ability [23], and enhance students' self-efficacy in learning [40], compared with traditional face-to-face education. These advantages contribute to students' future offline course learning. Another possible reason is the independent home environment for online learning during the pandemic, which greatly reduced the interaction among students. Interpersonal interaction among students is important in improving students' educational aspirations and academic performance [41]. A semester of home-based study might have created an urgent need for more social interaction and possibly increased students' enthusiasm, interest, and engagement in offline learning after they returned to school, thus promoting the improvement of student's academic performance.

It can be inferred that given the advancements in digital technology, college teaching activities are increasingly stepping into an era of highly open, diversified, and personalized education. Online education is not a "patent" under an "emergency" state nor a "one-off" tool and means of education; rather, it should be one of the choices and means of education under the "normal" state. No country in the world has launched such a large-scale online education system as China did, which puts the most rigid test on the software and hardware capabilities of technology [42]. The findings in this study show that the online education "experiment" was basically successful. Online education is good for the improvement of undergraduates' learning performance and outcomes in short and long periods. However, we suggest that online education cannot completely replace classroom education, especially for freshmen, as they have just entered school and prefer to take classes in the classroom. Senior students who carry out graduation projects may also hope to get face-to-face guidance from instructors.

The phased characteristics reflected in this study are a true portrayal of online education in China, but this is only at the beginning and preliminary stage, and a series of deep-seated problems involved in an "emergency" state still need to be solved in the post pandemic era. Most teachers lack experience in online teaching, and doing so during the pandemic was their first experience of such. Moreover, because of time constraints and insufficient preparation, teachers may not master online teaching methods well despite their efforts, thus affecting teaching quality [22]. In the post pandemic era, the global pandemic has recurred and abated a few times. Although students returned to the offline from the online class mode, they still yearn for the way of reviewing by watching videos repeatedly. In addition, for students who are unable to return to the campus in areas affected by the pandemic, online classes are the only choice for them to keep up with their studies. Universities are increasingly adopting online and offline-integrated teaching. Colleges and universities should encourage teachers to explore new teaching scenarios boldly, use high-tech teaching tools, and try new teaching modes such as flipping classes.

5. Conclusions

To be objective in observing and evaluating the relationship between emergency online education and students' learning outcomes during the COVID-19 pandemic, this study used large-scale panel data of 123,208 course scores of 2622 undergraduates from the classes of 2017–2021 in the School of Economics and Management in a Chinese university. Through horizontal and vertical comparison ANOVA across nine semesters, we found that students' course scores in the emergency online education semester fluctuated less

and improved substantially, and this improvement was more obvious for sophomores and juniors than for freshmen. Moreover, online education during the pandemic period significantly improved the course scores of undergraduates, especially sophomores, in the following one or two semesters.

However, the study is subject to some limitations. First, the data were gathered from students majoring in economics and management in a Chinese university; therefore, the conclusions are not necessarily representative of students from different cultures, countries, and specialties. Online education during the COVID-19 pandemic will probably bring challenges for specialized courses that require experimental teaching and hands-on practice. Moreover, the confounding variables include students' aptitude and discipline-specific variations. In addition, variations in pedagogies implemented across courses have yet to be addressed owing to the lack of primary data. Therefore, we cannot provide more explanations to interpret the research outcomes along these lines. Future research may combine large-scale data analysis with interviews, questionnaires, focus groups, and long-term follow-up experiments.

Author Contributions: J.G. developed the conceptualization and contributed to the formal analysis, methodology, software, and writing (original draft). S.X. and J.Y. contributed to the resources and data curation. N.Y. contributed the writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Teaching Demonstration Class Project of Anhui Province (2020SJJXSFK0918), the Key Teaching and Research Project of Anhui Province (2020jyxm0453), the Education Research Project of Coal Industry (2021MXJG051), and the 2022 Quality Engineering Project of Anhui Province (2021sx033).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data was obtained from Anhui University of Science and Technology and are available from the J. Geng with permission from Anhui University of Science and Technology.

Acknowledgments: The authors are grateful to the editors and reviewers, who provided valuable comments and suggestions to improve the quality of the paper significantly.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Multiple comparison tests of academic record grouping by semester.

Grouping [1]	Test Statistic	Standard Error	Standard Test Statistics	*p*-Value (Two-Sided Test)	Adj. *p*-Value [2] (Two-Sided Test)
2-3	−129.173	622.305	−0.208	0.836	1.000
2-4	−2357.231	622.005	−3.790	0.000	0.005
2-5	−2721.226	585.646	−4.647	0.000	0.000
2-6	−3027.965	584.087	−5.184	0.000	0.000
2-8	−4447.927	577.072	−7.708	0.000	0.000
2-9	−7955.762	573.632	−13.869	0.000	0.000
2-7	−8297.485	578.851	−14.334	0.000	0.000
2-1	11,792.619	726.142	16.240	0.000	0.000
3-4	−2228.058	488.940	−4.557	0.000	0.000
3-5	−2592.054	441.761	−5.868	0.000	0.000
3-6	−2898.792	439.692	−6.593	0.000	0.000
3-8	−4318.754	430.329	−10.036	0.000	0.000
3-9	−7826.589	425.706	−18.385	0.000	0.000
3-7	−8168.312	432.713	−18.877	0.000	0.000
3-1	11,663.446	615.999	18.934	0.000	0.000
4-5	−363.995	441.339	−0.825	0.410	1.000

Table A1. *Cont.*

Grouping [1]	Test Statistic	Standard Error	Standard Test Statistics	*p*-Value (Two-Sided Test)	Adj. *p*-Value [2] (Two-Sided Test)
4-6	−670.734	439.268	−1.527	0.127	1.000
4-8	−2090.696	429.896	−4.863	0.000	0.000
4-9	−5598.531	425.268	−13.165	0.000	0.000
4-7	−5940.254	432.281	−13.742	0.000	0.000
4-1	9435.388	615.696	15.325	0.000	0.000
5-6	−306.739	386.066	−0.795	0.427	1.000
5-8	−1726.700	375.368	−4.600	0.000	0.000
5-9	−5234.536	370.059	−14.145	0.000	0.000
5-7	−5576.259	378.098	−14.748	0.000	0.000
5-1	9071.392	578.941	15.669	0.000	0.000
6-8	1419.962	372.931	3.808	0.000	0.005
6-9	4927.797	367.586	13.406	0.000	0.000
6-7	5269.520	375.679	14.027	0.000	0.000
6-1	8764.654	577.363	15.180	0.000	0.000
8-9	−3507.836	356.334	−9.844	0.000	0.000
8-7	3849.559	364.676	10.556	0.000	0.000
8-1	7344.692	570.265	12.879	0.000	0.000
9-7	341.723	359.208	0.951	0.341	1.000
9-1	3836.857	566.785	6.770	0.000	0.000
7-1	3495.134	572.066	6.110	0.000	0.000

[1] The numbers (1–9) of the between-group difference comparison represent different semesters. Each row tests the null hypothesis that two semesters have the same distributions. [2] Significance values were adjusted by Bonferroni correction for multiple tests.

Table A2. Multiple comparison tests of academic record grouping by semester and grade.

Grade	Grouping [1]	Test Statistic	Standard Error	Standard Test Statistics	*p*-Value (Two-Sided Test)	Adj. *p*-Value [2] (Two-Sided Test)
2017	3-7	−63.125	280.947	−0.225	0.822	1.000
	3-2	748.434	196.916	3.801	0.000	0.004
	3-5	−1523.383	185.802	−8.199	0.000	0.000
	3-4	−1779.882	192.335	−9.254	0.000	0.000
	3-8	−1933.446	341.419	−5.663	0.000	0.000
	3-6	−2235.189	187.275	−11.935	0.000	0.000
	3-1	4093.667	195.329	20.958	0.000	0.000
	7-2	685.309	287.745	2.382	0.017	0.483
	7-5	1460.258	280.256	5.210	0.000	0.000
	7-4	1716.757	284.630	6.032	0.000	0.000
	7-8	−1870.321	400.735	−4.667	0.000	0.000
	7-6	−2172.064	281.235	−7.723	0.000	0.000
	7-1	4030.542	286.661	14.060	0.000	0.000
	2-5	−774.949	195.929	−3.955	0.000	0.002
	2-4	−1031.448	202.135	−5.103	0.000	0.000
	2-8	−1185.013	347.035	−3.415	0.001	0.018
	2-6	−1486.755	197.326	−7.535	0.000	0.000
	2-1	3345.233	204.986	16.319	0.000	0.000
	5-4	256.499	191.325	1.341	0.180	1.000
	5-8	−410.064	340.851	−1.203	0.229	1.000
	5-6	−711.806	186.237	−3.822	0.000	0.004
	5-1	2570.284	194.335	13.226	0.000	0.000
	4-8	−153.564	344.456	−0.446	0.656	1.000
	4-6	−455.307	192.756	−2.362	0.018	0.509
	4-1	2313.785	200.590	11.535	0.000	0.000

Table A2. *Cont.*

Grade	Grouping [1]	Test Statistic	Standard Error	Standard Test Statistics	*p*-Value (Two-Sided Test)	Adj. *p*-Value [2] (Two-Sided Test)
	8-6	−301.743	341.656	−0.883	0.377	1.000
	8-1	2160.221	346.137	6.241	0.000	0.000
	6-1	1858.478	195.743	9.494	0.000	0.000
2018	3-7	−1717.650	212.930	−8.067	0.000	0.000
	3-8	−948.656	210.048	−4.516	0.000	0.000
	5-4	1610.834	207.775	7.753	0.000	0.000
	5-8	−3287.169	194.589	−16.893	0.000	0.000
	5-6	−2070.577	197.313	−10.494	0.000	0.000
	4-8	−1676.335	202.450	−8.280	0.000	0.000
	4-6	−459.743	205.070	−2.242	0.025	0.524
	5-9	−1326.455	284.331	−4.665	0.000	0.000
	5-3	2338.513	215.184	10.867	0.000	0.000
	5-7	−4056.163	197.697	−20.517	0.000	0.000
	9-4	284.379	289.767	0.981	0.326	1.000
	9-6	−744.122	282.360	−2.635	0.008	0.176
	9-3	1012.058	295.125	3.429	0.001	0.013
	9-8	1960.714	280.463	6.991	0.000	0.000
	9-7	2729.708	282.629	9.658	0.000	0.000
	4-3	727.679	222.318	3.273	0.001	0.022
	4-7	−2445.330	205.440	−11.903	0.000	0.000
	6-3	267.936	212.573	1.260	0.208	1.000
	6-8	1216.592	191.698	6.346	0.000	0.000
	6-7	1985.586	194.852	10.190	0.000	0.000
	8-7	768.995	192.094	4.003	0.000	0.001
2019	7-5	1963.737	157.842	12.441	0.000	0.000
	6-8	312.420	153.528	2.035	0.042	0.419
	6-7	−382.972	155.742	−2.459	0.014	0.139
	8-7	70.552	146.383	0.482	0.630	1.000
	6-9	1355.058	152.071	8.911	0.000	0.000
	6-5	2346.708	164.490	14.267	0.000	0.000
	8-9	−1042.638	142.471	−7.318	0.000	0.000
	8-5	2034.288	155.658	13.069	0.000	0.000
	7-9	−972.086	144.853	−6.711	0.000	0.000
	9-5	991.650	154.221	6.430	0.000	0.000
2020	9-7	1655.092	88.745	18.650	0.000	0.000
	8-7	1752.246	91.660	19.117	0.000	0.000
	8-9	−97.154	86.900	−1.118	0.264	0.791

[1] The numbers (1–9) of the between-group difference comparison represent different semesters. Each row tests the null hypothesis that two semesters have the same distributions. [2] Significance values were adjusted by Bonferroni correction for multiple tests.

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