A comparative analysis of student performance outcomes in online and in-person classes

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Abstract

The COVID-19 pandemic energized a wave for online education that had started a couple of decades earlier [1] which has persisted beyond the pandemic. Seventy one percent of students surveyed in 2021 reported they would continue at least some form of online learning even post-pandemic [2]. The popularity of online degree programs promises to continue in the future and many universities are experimenting in the fully online space. However online teaching, particularly teaching quantitative subjects, can be challenging. Ultimately, academic programs and faculty must ensure students enrolled in online courses have the same learning outcomes as in-person students. The question examined in this study is whether online education impacts learning outcomes in a quantitative introductory statistics course. This is an extension of a previous study [3] that examined performance outcomes of students in asynchronous online sections of a required introductory statistics course to that of sections where the students attended class in person and compared overall performance of online v. in-person sections on homework, take-home midterm exam, and proctored final exam. The study also compared overall performance in take-home midterm vs. proctored final exams.

This is an important topic for engineering management programs and faculty because knowledge of probability and statistics is required for managing quality management systems, which is a domain in the Engineering Management Body of Knowledge (EMBoK) published by the American Society for Engineering Management. This paper presents a summary of those findings but extends the analysis to a more granular level. It compares the performance of online and in-person sections for homework in four major course topics: Descriptive Statistics, Inferential Statistics, Simple and Multiple Regression, and fundamentals of Project Management. Findings will help determine whether instruction mode is a factor that impacts effectiveness of student learning for various content and topics. We will use parametric and nonparametric tests of mean and validate their assumptions using tests for normality and homogeneity of variance as our tools for analysis to capture findings.

Literature Review

A survey of college instructors and administrators involved in online teaching showed the popularity of online learning, rise of blended learning, and growing share of the women among online instructors [4]. Respondents expected growth of online and blended learning. Student success factors in online learning were associated with training to self-regulate, better measurement of student readiness, better evaluation of achievements, and course management system. Another study on a graduate-level introductory biostatistics course compared online versus traditional in-person classroom learning environments [5]. This study found online class students' quiz scores to be only 2.5% lower than those in the traditional classroom but the final exam average 0.9% higher. The study concluded that student performance was comparable in both modes of instruction.

A summary of studies that compared outcomes between online and in-person statistics courses [6] found that student achievement in online classes is on par with in-person class. However, overall student satisfaction was higher in in-person classes. A study of the quality and extent of online education in the United States [7] found that 40.7% of schools offering online courses believe that students are more satisfied with online classes compared to traditional classes, and only 3.1% of the schools disagreed with that statement. Medium and large schools reported higher satisfaction and the small schools the lowest. The same study found that 53.6% of schools believe online education is critical to their future. Most academic leaders in this study believed that online learning is equal or even superior to in-person instruction.

Another comparison of online and in-person [8] concluded that students appreciated online learning for its clear and coherent structure of the material, supporting self-regulated learning, and distributing information. Preference of in-person classes was due to providing a shared understanding and interpersonal relations established. A study of learning preferences during the COVID-19 pandemic [9] found student preferences for online courses to be based on the course subject, perceived to be easier, as well as providing higher flexibility, comfort, and convenience. In contrast, more difficult subjects, and those in the student's major discipline of study, are preferred to be taken in-person.

We find the present study to be quite unique due to the large dataset and controlled approach in course design and delivery, and student assessments. These factors make the comparison of performance in online versus in-person sections meaningful and informative.

Methodology and summary of findings

Data was tracked from 55 online and in-person sections during four years of instruction, including summer classes. Sections were taught by different instructors; however, the exams were team-developed to maintain consistency across all sections. This helps to avoid teaching to the test, reduces variance in grading by maintaining an objective (multiple-choice) format, and uses similar testing criteria and parameters.

Results were pooled into two groups, in-person and online learning modes and average performance of each group were compared to assess the effectiveness of the two modes of instruction. Exhibit 1 shows the number of sections for each modality in various years and terms. In total, this study included 45 online sections and 10 in-person sections of the course which represent population data*, not sample data*.

Exhibit 1: Number of online and in-person sections of the course

	Fall		***Winter***		***Spring***		***Summer***	
Year	**Online**	**In-Person**	**Online**	**In-Person**	**Online**	**In-Person**	**Online**	**In-Person**
1	4	1	1					
2	3	1	2		4	1	2	
3	3	1	5	1	4	2	3	1
4	4		3		5	2	2	

While discussion and case analysis were among assignments that contributed to course grade, only data from assignments that were objectively graded with multiple-choice assessments were included in the study, namely homework and exams. Also included for comparison were end-of-course grade point averages for online and in-person delivery modes (adjusted to include only homework and exams). Exhibit 2 shows a summary of findings. The statistical tool used was Z-test of two means with known variances. In all cases, the null hypothesized no difference between online and in-person sections, and the alternative hypothesized inequality between the two.

Exhibit 2: Online and in-person modes - student performance dimensions

	Online N = 536	In-person N = 188	p-value	Conclusion At 0.05 alpha value
Homework avg. (max = 30)	25.72	25.9	0.11	No difference statistically
Midterm exam avg. (max = 100)	78.6	80.2	0.16	No difference statistically
Final exam avg. (max = 100)	73.7	73.8	0.94	No difference statistically
Mean course average (max 100)	78.6	79.3	0.4	No difference statistically

Since the midterm was a take-at-home test and the final was proctored, a paired t-test was used to compare online and in-person section averages. Results are summarized in Exhibit 3.

Exhibit 3: Online and in-person scores for take-home midterm and proctored final

	Online N = 536	In-person N = 188	Aggregate N = 724	Conclusion at 0.05 alpha value
Take-home exam	78.6	80.2	79	7.87 E-17 (Significant at 0.05 level)
Proctored final	73.7	73.8	73.7	2.11 E-8 (Significant at 0.05 level)
Difference	4.9	6.4	5.3	9.4 E-24 (Significant at 0.05 level)

Statistically, it appears that take-home exam performance was higher than proctored final exam. However, different testing parameters may explain those outcomes as summarized in Exhibit 4.

Exhibit 4: Different Testing parameters for midterm versus final exam

	Midterm	Final
Timed nature of exam	3 Days	3 Hours
Coverage of content	5 chapters	Cumulative; all 10 chapters
Resources allowed	Book, notes, videos, other resources	Book and notes
Technology allowed	Computer with Excel, and calculator	Only Calculator
Testing Conditions	Take at home, NOT proctored	In-person; In room with proctor

Detailed analysis of Homework Scores

The analysis presented earlier centers around the performance of online and in-person sections on homework, exams, and course averages and found no statistically significant difference among online and in-person sections. We wanted to determine if overall student performance on

the various course topics varied. This is best analyzed by comparing grades on homework related to various course topics. Specifically, for the topics covered in the course students had to complete an objective homework (multiple choice) related to each chapter as listed in Exhibit 5.

Exhibit 5: Chapter titles for the weekly homework

Homework	Topic
1	Data and Statistics
2	Tabular and Graphical Summaries
3	Numerical Measures
4	Introduction to Probability
5	Discrete Probability Distributions
6	Continuous Probability Distributions
7	Simple Linear Regression
8	Multiple Regression.
9	Forecasting: Time series and Regression
10	Project Management

Previously, we found that overall homework average scores of online and in-person sections revealed no statistically significant difference, but we then explored differences for student performance on the homework for the ten topics shown in Exhibit 5.

Homework Analysis Results and Discussion

We pooled each assignment's grades from all classes and compared the means to verify the significance of difference between the level of challenge these assignments posed to students. Our observations provided evidence for significant differences between the mean assignment grades. Exhibit 6 shows the summary table of ANOVA test that compared the mean grades between the ten homework assignments and returned a p-value of 7.91e-93. Homework "2" averaged the highest score, while homework "1" averaged the lowest score.

Exhibit 6: ANOVA results – pooled homework average for online students
(P-value of ANOVA is 7.91e-93)

Groups	*Count*	*Sum*	*Average*	*Variance*	
HW1	536	13724	25.60	19.60	Data and Statistics
HW2	536	14124	26.35	24.10	Tabular and Graphical Summaries
HW3	536	13575	25.33	24.43	Numerical Measures
HW4	536	13662	25.49	20.95	Introduction to Probability
HW5	536	13500	25.19	26.44	Discrete Probability Distributions
HW6	536	13351	24.91	23.38	Continuous Probability Distributions
HW7	536	12931	24.13	29.28	Simple Linear Regression
HW8	536	13967	26.06	32.01	Multiple Regression.
HW9	536	12375	23.09	36.82	Forecasting: Time series and Regression
HW10	536	12615	23.54	29.35	Project Management

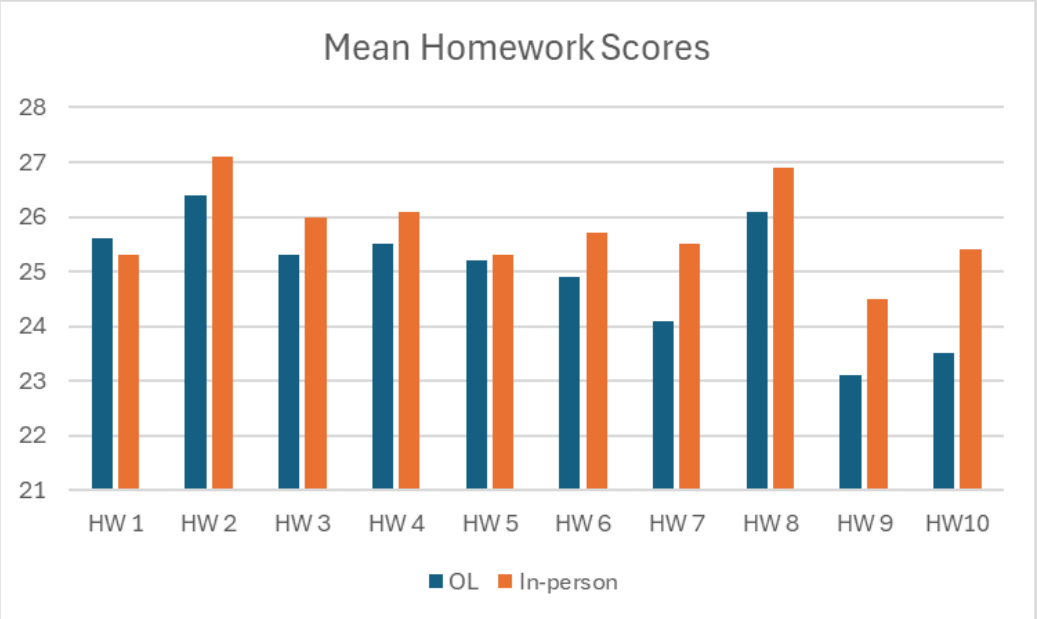
We repeated the ANOVA test for in-person classes to compare the level of assignment challenge between online and in-person classes. There is a similar pattern, but not identical in the results. The p-value of 1.96e-08 provides statistically significant evidence for differences between the mean assignment grades. Like the online classes, assignments "2" and "8" rank the highest for in-person classes, assignment "9" the lowest, but assignment "10" is not among the two lowest averages. Exhibit 7 is the summary of ANOVA test for in-person mean assignment grades.

Exhibit 7: ANOVA results – pooled homework average for in-person students
(P-value of ANOVA is 1.96e-08)

Groups	*Count*	*Sum*	*Average*	*Variance*	
HW1	188	4759	25.31	18.22	Data and Statistics
HW2	188	5095	27.10	14.86	Tabular and Graphical Summaries
HW3	188	4879	25.95	11.84	Numerical Measures
HW4	188	4906	26.10	14.02	Introduction to Probability
HW5	188	4753	25.28	35.68	Discrete Probability Distributions
HW6	188	4828	25.68	22.13	Continuous Probability Distributions
HW7	188	4788	25.47	22.76	Simple Linear Regression
HW8	188	5062	26.93	29.24	Multiple Regression.
HW9	188	4597	24.45	22.53	Forecasting: Time series and Regression
HW10	188	4779	25.42	34.53	Project Management

Exhibit 8 shows the difference in average scores for online and in-person sections for each of the ten homework assignments in the course. Students in the in-person sections had higher average scores for homework 2 through homework 10.

Exhibit 8: Mean homework grades in online and in-person classes



To determine if those differences were statistically significant a one-tailed t-test was run for all assignments to compare the pairs of assignments between online and in-person classes. The null hypothesized that students in residential classes perform better than those in online settings. Exhibit 9 shows the results which indicate statistically significant difference between online and in-person classes in most homework assignment. Average student grade in residential classes was between 0.1 to 1.9 points better than online sections. Students in online classes performed better than in-person classes only in one assignment by 0.3 point.

Exhibit 9: One-tailed paired t-test. Average homework scores online & in-person sections

Homework	T-test P-value	*Mean In-Person*	*Mean Online*	*Delta*	
HW1	0.22	25.3	25.6	-0.3	Data and Statistics
HW2	0.05	27.1	26.4	0.7	Tabular and Graphical Summaries
HW3	0.05	26.0	25.3	0.7	Numerical Measures
HW4	0.06	26.1	25.5	0.6	Introduction to Probability
HW5	0.46	25.3	25.2	0.1	Discrete Probability Distributions
HW6	0.03	25.7	24.9	0.8	Continuous Probability Distributions
HW7	0.001	25.5	24.1	1.4	Simple Linear Regression
HW8	0.03	26.9	26.1	0.8	Multiple Regression.
HW9	0.003	24.5	23.1	1.4	Forecasting: Time series and Regression
HW10	3.3e-05	25.4	23.5	1.9	Project Management

Normal distribution and homogeneity of variances are basic assumption for both parametric tests used in this study, ANOVA and Student's T. Grade distributions are mostly left-skewed. Robustness of the F-test in ANOVA has been a point of controversy among statisticians Researchers simulated a variety of distributions where in 100% of cases, F-test provided robust results [10]. We used Shapiro-Wilk test to verify normality of grade distributions and visualized residuals using Quantile-Quantil plot. Shapiro-Wilk test of normality p-value for all classes is far below the threshold of 0.05 which severe deviation from normal distribution. This is consistent with the sample Quantile-Quantile plot demonstrated in Exhibit 10.

Exhibit 10: Quantile-Quantile plot of residuals of homework grades

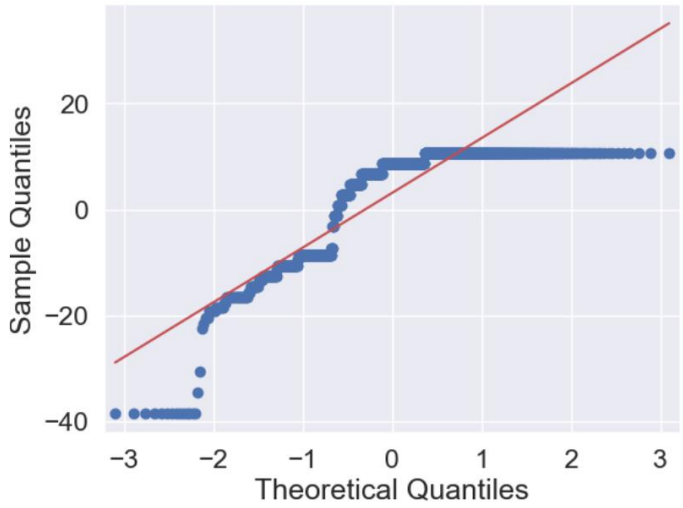


Exhibit 11 demonstrates the Shapiro-Wilk test results for all assignment grades. These results indicate none of the class grades are normally distributed. This evidence fails one of the basic assumptions of ANOVA and t-test.

Exhibit 11: Shapiro-Wilk test of normality results for all classes

	P-Value		
	Online	**In-Person**	
HW1	1.23e-25	1.16e-14	Data and Statistics
HW2	3.76e-31	7.07e-20	Tabular and Graphical Summaries
HW3	7.41e-27	5.92e-09	Numerical Measures
HW4	2.61e-26	1.98e-15	Introduction to Probability
HW5	1.74e-26	2.19e-19	Discrete Probability Distributions
HW6	4.10e-24	4.77e-16	Continuous Probability Distributions
HW7	1.72e-20	1.79e-13	Simple Linear Regression
HW8	1.77e-29	3.32e-21	Multiple Regression.
HW9	1.02e-22	1.33e-10	Forecasting: Time series and Regression
HW10	4.30e-19	8.84e-17	Project Management

A Levene's test of all classes' homework grades checks for homogeneity of variances which is another basic assumption of parametric tests of mean. The p-value of 0.53 indicates there is no statistically significant differences between variances of homework grades. Since the test results for one of the basic assumptions of parametric tests of mean failed to meet the requirement, we performed the non-parametric Mann-Whitney test to compare the pairs of homework results from online and in-person classes. This analysis found the mean grades of homeworks 6-10 show a statistically significant difference between online and residential classes. Residential class grade means are between 0.8 and 1.9 points higher than the online students.

Exhbit 12: Mann-Whitney test results

	U	P	
HW1	102127.5	0.061849	Data and Statistics
HW2	93343	0.737618	Tabular and Graphical Summaries
HW3	98743	0.307552	Numerical Measures
HW4	96372.5	0.669808	Introduction to Probability
HW5	96087	0.722833	Discrete Probability Distributions
HW6	93338.5	0.738439	Continuous Probability Distributions
HW7	93198.5	0.712189	Simple Linear Regression
HW8	105327	0.004872	Multiple Regression.
HW9	96481.5	0.650936	Forecasting: Time series and Regression
HW10	77992	3.05E-05	Project Management

Conclusions and Recommendations

Earlier studies found no difference between performance of online and in-person students on homework, exams, and course grade point average. On the other hand, this study dived deep into the various course subjects and student performance on related homework. We found differences between performance of online and in-person groups on seven of the 10 homework assignments.

The same teaching strategies were used in all 10 modules.We had provided notes, examples, and screen-capture videos for all course modules in online classes. Lower student performance in 70% of assignments in online sections could be the result of high visual contents or complexity of solution process in these modules. These results warrented providing more exercises and video demonstrations covering examples of solution processes for students in online classes. Students' engagement in online courses can impact their learning process. Adopting methods that encourage engagement can improve learning outcomes. Required discussion board and peer to peer interaction can create a dynamic community of learning and communication both with instructor and classmates. Syncronous video conferencing with instructor also can return immediate feedback, improve learning and increase student retention.

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