**The Effect of Online Learning on Student Performance:**

**A Replication Analysis of: *A Randomized Assessment of Online Learning (Alpert et al., 2016)***

Data Analysis Project Proposal

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HUDM 5123: Linear Models and Experimental Designs

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**Context**

**Introduction**

The data presented in this proposal were originally published in *A* *Randomized Assessment of Online Learning* (Alpert et al., 2016). In the original study, the researchers conducted a randomized study that examined the effect of instructional format on learning outcomes of college students. In particular, Alpert et al. (2016) examined the effect of three different learning formats (e.g. face-to-face, hybrid, and purely online) on students’ cumulative final grade in a university-level economics class.The researchers found that students’ final grades were significantly different across traditional, hybrid, and purely online learning formats. Specifically, students in the online learning condition received final grades that were, on average, four to five points lower than students in the traditional, in-person lecture format after controlling for prior GPA and SAT scores, as well as prior student credit hours.

Alpert et al. (2016)’s study is part of a substantial body of educational research that has examined the impact of online learning on student performance (Bowen et al., 2014; Figlio et al., 2013). Yet, despite the wealth of research on the effects of online learning, Alpert et al. (2016)’s study is among only a handful of randomized experiments in this literature. Moreover, their findings are particularly relevant today as universities are considering the costs and benefits of increasing online learning offerings for students, especially during the COVID-19 pandemic. Therefore, in light of the timely importance of research on hybrid and virtual learning effectiveness, this paper replicates Alpert et al. (2016)’s analysis to evaluate researchers’ original findings. Specifically, I will examine the effect of instructional format on the final course grades that students received (RQ1). In addition, GPA will be incorporated as a covariate in the relationship between instructional format and final grades. (RQ2). Finally, multiple comparisons will be conducted to examine pairwise differences in adjusted group means for final course grades conditioned on prior GPA.

**Methods**

* describe how were data collected

Data from the Alpert et al. (2016) study was made publicly available and accessed online at Open ICPSR.org. The data sample in Alpert et al. (2016) was collected over four consecutive 16-week semesters at a largest university in the Northeast. Each semester, a course in microeconomics was offered with three sections. After signing up for the course, students were randomly assigned to one of three instructional formats; face-to-face classroom instruction, hybrid, and online. Students assigned to the face-to-face instructional format received traditional classroom instruction. For example, in in this condition, students attended two weekly lectures in-person for the entirety of the semester. In the hybrid format, students met in-person for one lecture per week and then were given online lecture materials to in place of a second in-person lecture. Finally, students assigned to the online format were provided the same online lecture materials as the hybrid section but were not given an in-person lecture. For each of the three conditions, lectures and instructional content were prepared and delivered by the same instructor.

The dependent variable in the Alpert et al. (2016) study the cumulative final grade that students received in the course. Cumulative grades were measured continuously out of 100 points total. In addition to analyzing the relationship between instructional format (IV) and cumulative grade (DV), the researchers also accessed university records to measure prior GPA as a continuous covariate. In total, 323 students completed the course across the three instructional format conditions.

* describe how will they be analyzed, including methods and their assumptions (with equations)

The first research question evaluated in this replication study was the the effect of instructional format on students’ final grades. To test the null hypothesis that instructional format had no effect of final course grades, a one-way ANOVA was conducted. Before conducting the one-way ANOVA, assumptions for analysis of variance (e.g. LaTex) were assessed. Interpretation of the following tests of assumptions and their corresponding figures are presented in the Results section.

First, examining the assumption of constant variance, the variance of students’ final course scores were examined at all levels of instructional format. To do so, Maxell et al. (2017)’s variance ratio was computed, which compares the ratio of the largest group variance to the smallest group variance. Maxwell et al. (2017) point out that in the case of unequal-n, which is true of the data obtained for this replication study, violations of the assumption of constant variance are more problematic. Therefore, the interpretation of the findings of the variance ratio reported in the Results section are of key importance. In addition, the assumption of constant variance was evaluated with Levene’s test, which evaluated the null hypothesis that the group variances for the outcome variable, final course scores, are identical across the experimental conditions. The next assumption for analysis of variance assessed was normality. To test normality, a QQ-plot of the residuals was plotted to inspect whether the sample data were normally distributed. Additionally, following visual inspection of the QQ-plot, a Shapiro-Wilk test was also conducted to test the null hypothesis that the data in each group were normally distributed.

After checking assumptions, an omnibus test of the null hypothesis was conducted utilizing a general linear *F* test and a model comparison framework. In particular, the following full and restricted models tested the null hypothesis that there is no effect of instructional format on final course grades compared the following full and restricted models:

Full: *Yi* = μ + α*j* + ε*ij*

Restricted: *Yi* = μ + ε*ij*

where Y*i* represents final course grade for student *i* in the *j*th group, μ represents the unweighted average final course grade across instructional formats, α*j* represents the treatment effect of instructional format for the *j*th group, and where εij represents the random error associated with student *i* in the *j*th group. After conducting an omnibus test of the null hypothesis by conducting a one-way ANOVA omnibus, an one-way ANCOVA was conducted to examine the effect of instructional format on final course grades when controlling for prior GPA. Before conducting the one-ANCOVA, additional assumptions specific to analysis of covariances were evaluated. First, in order to determine whether prior GPA was suitable as a covariate, the correlation between prior student GPA and final course grade was calculated. Covariate suitability based on correlation strength was evaluated with regards to recommendations stated in the literature, which recommend a covariate-outcome correlation of *r* ≥ .3 (Maxwell et al., 2017). Next, in order to determine whether random assignment was effective and to ensure covariate balance at baseline, prior GPA was compared across all three instructional format. In particular, to test for covariate balance at baseline, Maxwell et al. (2017)’s variance ratio was computed. Additionally, Levene’s test of homogeneity of variance was conducted to test the null hypothesis that the group variances for prior GPA were identical across all three levels of instructional format. Finally, in order to test the assumption of no treatment by covariate interaction, an ANCOVA model containing an interaction term was fitted, and the interaction term was evaluated for statistical significance. The full and restricted models that were compared to test treatment by covariate interaction were as follows:

Full: *Yi* = μ + α*j* + β1*X*ij + β2*X*ij\*α*j* + ε*ij*

Restricted: *Yi* = μ + β*Xij* + ε*ij*

where the null hypothesis stated that β2 = 0, representing that there is no significant effect of the interaction of instructional format (α*j*) and prior GPA (*X*i*j*) on final course grade for the *i*th student in the *j*th group.

After checking assumptions for the inclusion of prior GPA as a covariate, a one-way ANCOVA was conducted to examine the effect of instructional format on final course grade while controlling for prior GPA. The following full and restricted models were compared for the one-way ANCOVA omnibus null hypothesis:

Full: *Yi* = μ + α*j* + β*X*ij + ε*ij*

Restricted: *Yi* = μ + β*Xij* + ε*ij*

where Y*ij* represents student final course grade for the *i*th participant in the *j*th group, μ represents the grand mean, α*j* represents the group mean of the treatment variable, instructional format, for the *j*th group β represents the population regression coefficient for prior GPA, X*ij* represents prior GPA for the *i*th participant in the *j*th group, and εij represents the error term for the same participant. After the one-way ANCOVA omnibus test of the null hypothesis was conducted, pairwise comparisons of adjusted group means were conducted to examine all possible contrasts, or differences in adjusted group means, for each level of instructional format. For example, the equation for the pairwise comparison of the adjusted group means of virtual and hybrid instructional formats while conditioning on prior GPA is as follows:

ψ1 =1μvirtual −1μhybrid + 0μtraditional

where ψ1 represents the difference in adjust group means in students’ final course grades between the virtual and hybrid instructional formats, 1μvirtual represents the adjusted group mean of final course grade conditioned on prior GPA for participants in the virtual instructional format, and 1μhybrid represents the adjusted group mean of final course grade conditioned on prior GPA for participants in the hybrid instructional format.

* describe how Type I error rate will be managed (these latter two parts should be more technical in this project than they would be in, say, a typical research paper, because the focus of this course is on the methods, per se)

Finally, the following considerations were made in order to control the Type I error rate at α = .05. First, with regards to the tenability of the assumption of constant variance, a Welch-Satterthwaite correction was utilized to correct for inverse pairings… Additionally, for pairwise comparisons of adjusted group means, Tukey’s HSD correction was applied to maintain the familywise Type I error rate at α = .05.

**Results**

* discuss tenability of assumptions with evidence including plots and/or statistical tests,
* To test the assumption of constant variance of final course grades for one-way ANOVA with unequal-n size, Maxwell et al. (2017)’s variance ratio was computed. Specifically, the product of the largest ratio of variances and the ratio of the largest group size to the smallest group size was calculated and observed to be less than 4, providing evidence for heterogeneity of variance. In addition, the ANOVA assumption of constant variance was evaluated with Levene’s test of homogeneity of variance. The results were not significant, *F*(1,272) = 1.99, *p* = .14), indicating that there was insufficient evidence to reject the null hypothesis of constant variance. As a third indicator of group variances, a boxplot of students’ final course grade by experimental condition were visualized in Figure 1. Similar to the outcome of the variance ratio statistic and Levene’s test, visual inspection of Figure 1 suggested similar group variances across all three treatment levels.

**Figure 1**

*Boxplot of Final Course Grade by Instructional Format*

Chart, box and whisker chart

Description automatically generated

* Visual inspection of the boxplots revealed that there were outliers in final course grades. To test whether outliers were statistically significant, Grubb’s test was conducted to test the null hypothesis that the lowest scores in the data set were not outliers. Grubb’s test evaluates the lowest score sequentially. This means that the two final course grades of 0 were evaluated first to test the null hypothesis that they were not significantly significant outliers.
* Grubb’s test of the null hypothesis that 0 was not a significant outlier in final course grade revealed that the results were significant *G* = 6.59, *p* < .001, providing evidence that the values of 0 were statistical outliers. These values were removed from the data set. A second iteration of Grubb’s test was conducted and provided no evidence that there were outlier scores in the remaining final course grades, *G* = 3.02, *p* = .31.
* Next, to test the assumption of normality, a QQ plot of residuals of students’ final course grade was generated (Figure 2). Visual inspection of the Figure 2 revealed that the sample data appears to be normally distributed with a few outliers in the lowest quantiles

**Figure 2**

*QQ Plot of Residuals for Final Course Grade*

Chart, line chart

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* In addition, a density plot of final course grade by instructional format (Figure 3) also provided evidence that grades were normally distributed.

**Figure 3**

*Density Plot of Final Course Grade by Instructional Format*

Chart, histogram

Description automatically generated

* Following assumption tests, a one-way ANOVA was conducted to test the null hypothesis that there is no effect of instructional format on final course grades. Results from the one-way ANOVA reported in Table 1 indicated that the effect of instructional format was significant, *F* (1,272) = 5.61., *p* < .01). These results suggest that students’ final course grades were significantly different across instructional format, providing evidence to reject the null hypothesis.

**Table 2**

*Fixed-Effects ANOVA with Final Course Grade as Criterion*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Predictor | Sum  of  Squares | *df* | Mean  Square | *F* | *p* | partial η2 | partial η2  90% CI  [LL, UL] |
| (Intercept) | 572704.92 | 1 | 572704.92 | 6250.42 | .000 |  |  |
| format\_type | 713.97 | 2 | 356.99 | 3.90 | .021 | .03 | [.00, .06] |
| Error | 24739.19 | 270 | 91.63 |  |  |  |  |

*Note.* LL and UL represent the lower-limit and upper-limit of the partial η2 confidence interval, respectively.

* Following the one-way ANOVA omnibus test of the null hypothesis, assumptions for analysis of covariance were tested.
* Specifically, in order to determine covariate suitability for students’ prior GPA, the correlation between prior GPA and final course grade was calculated. Results indicated that prior GPA and final course grade were strongly correlated *r*(273) = .39, *p* < .001, providing initial support for the use of prior GPA as a covariate.
* In addition, a scatterplot of the relationship between prior GPA and final course grade (Figure 4) revealed that the relationship between the covariate and outcome were linear.

**Figure 4**

*Scatter Plot of Course Grade by GPA*

Chart, scatter chart

Description automatically generated

* Next, the assumption of covariate balance was tested by comparing group variances of prior GPA across all three levels of the treatment variable.
* To test constant variance of prior GPA across experimental groups, Maxwell et al. (2017)’s variance ratio was computed. Specifically, the product of the largest ratio of variances and the ratio of the largest group size to the smallest group size was calculated and observed to be less than 4, providing evidence for heterogeneity of variance of prior GPA.
* Additionally, a boxplot of prior GPA by treatment group (Figure 5) provided visual evidence that students’ prior GPA was balanced at baseline, suggesting successful random assignment to experimental groups in the study.
* Finally, the assumption of no treatment by covariate interaction was tested by fitting a regression model with an interaction term between instructional format and prior GPA. Results for a test of treatment by covariate interaction are presented in Table 3.

**Figure 5**

*Prior GPA by Instructional Format*

Chart, box and whisker chart

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**Table 3**

*Fixed-Effects ANOVA with Instructional Format by Prior GPA Interaction Term*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Predictor | Sum  of  Squares | *df* | Mean  Square | *F* | *p* | partial η2 | partial η2  90% CI  [LL, UL] |
| (Intercept) | 6335.07 | 1 | 6335.07 | 81.35 | .000 |  |  |
| Format type | 279.65 | 2 | 139.82 | 1.80 | .168 | .01 | [.00, .04] |
| GPA | 1968.83 | 1 | 1968.83 | 25.28 | .000 | .09 | [.04, .14] |
| Format Type\*GPA | 377.00 | 2 | 188.50 | 2.42 | .091 | .02 | [.00, .05] |
| Error | 20792.64 | 267 | 77.88 |  |  |  |  |

*Note.* LL and UL represent the lower-limit and upper-limit of the partial η2 confidence interval, respectively.

* A test of the assumption that there is no interaction between instructional format and prior GPA revealed that there was no evidence of treatment by covariate interaction *F*(2,267) = 2.42, *p* = .09.
* Following tests of assumptions for covariate inclusion, an ANCOVA was conducted with final course grade as the dependent variable and instructional format as the independent variable while controlling for prior GPA as a covariate. Results are presented in Table 4.

**Table 4**

*Fixed-Effects ANCOVA with Final Course Grade as Criterion*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Predictor | Sum  of  Squares | | *df* | Mean  Square | *F* | *p* | partial η2 | partial η2  90% CI  [LL, UL] |
| (Intercept) | 22122.02 | 1 | | 22122.02 | 281.10 | .000 |  |  |
| Format Type | 550.41 | 2 | | 275.20 | 3.50 | .032 | .03 | [.00, .06] |
| GPA | 3569.55 | 1 | | 3569.55 | 45.36 | .000 | .14 | [.08, .21] |
| Error | 21169.64 | 269 | | 78.70 |  |  |  |  |

*Note.* LL and UL represent the lower-limit and upper-limit of the partial η2 confidence interval, respectively.

* Results indicated that the effect of instructional format on final course grade, while controlling for GPA, was significant, F(2,269) = 3.5, p = .03, providing evidence to reject the null hypothesis that instructional format has no effect on the final grades that students receive in the course.
* Following a one-way ANCOVA, pairwise contrast were conducted to compute the estimated marginal means for final course grades while controlling for prior GPA (e.g. adjusted group means).
* Pairwise comparisons of adjusted group means were performed with a Tukey’s HSD adjustment for familywise Type 1 error rate.
* The adjusted group mean of final course grade while controlling for prior GPA was statistically significantly greater in the traditional instructional format (79.5 ± 3.6) compared to the online instructional format (76.1 ± 3.8).
* The pairwise comparison of traditional instructional format to hybrid format was not significant. Additionally, the pairwise comparison of hybrid format to online format was not significant.
* Thus, the pairwise comparisons provide evidence that students in the traditional in-person instructional performed better in the course overall compared to students in the online instruction condition.
* discuss results in text and with tables and plots (see APA Publication Manual checklists for formatting),

**Discussion**

* interpret results and draw conclusions
* discuss limitations
* discuss future research, if applicable

**References**

**Appendix**

* Include commented computer code (can copy/paste or knit to PDF and paste)
* GitHub repo

**Variables**

The randomized treatment variable in this study was instructional format. Students interested in taking a college-level economics were randomly assigned one of three instructional format conditions; face-to-face classroom instruction, hybrid, and online. Students assigned to the face-to-face instructional format received traditional classroom instruction. For example, in in this condition, students attended two weekly lectures in-person for the entirety of the semester. In the hybrid format, students met in-person for one lecture per week and then were given online lecture materials to in place of a second in-person lecture. Finally, students assigned to the online format were provided the same online lecture materials as the hybrid section but were not given an in-person lecture. For each of the three conditions, lectures and instructional content were prepared and delivered by the same instructor.

The dependent variable in the Alpert et al. (2016) study the cumulative final grade that students received in the course. Cumulative grades were measured continuously out of 100 points total. In addition to analyzing the relationship between instructional format (IV) and cumulative grade (DV), the researchers also measured GPA and SAT as covariates. GPA and SAT were both measured continuously. For SAT scores, Alpert et al. (2016) controlled for both verbal reasoning and math SAT scores. Finally, the researchers also controlled for student demographics (e.g. race, gender) as well as cumulative university credits that students had acquired prior to enrolling in the course.

**Missing Data**

Alpert et al. (2016) randomly assigned students to instructional format conditions prior to the beginning of the semester. This meant that, naturally, not all students who were given permission to enroll in the class decided to enroll. Moreover, not all of the students who enrolled in the course completed the course. Therefore, there are two measures of attrition that are captured in the data set; ‘not enrolled’ and ‘dropped course’. Descriptive statistics for measures of attrition, “Did Not Enroll” and “Dropped Course”, are presented in Table 1 along with the total group sample size randomly assigned to each condition as well as the final group sample size at the end of the study.

**Table 1**

*Attrition by Group*

Table

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The researchers chose following recommendations from similar randomized experiments on online learning, hence the decision to randomly assign participants to condition prior to the start of the school semester (Bowen et al., 2014; Figlio et al., 2013; Joyce et al., 2015). Doing so enabled the researchers to also control for and examine whether the mode of instructional format offered to students had an effect on nonenrollment and course drop out. Students that were randomly assigned to the option of taking the class online dropped the course at higher rates than students in the hybrid and traditional lecture formats. Alpert et al. (2016) used this attrition data in the original study to control for the possible confound of the effect of differential attrition. When controlling for attrition, the researchers found the same similar group mean estimates for final grade received and the same statistical significance obtained in an ANCOVA test without an attrition term included.

In addition to final grades, there are also missing records in the data set for student GPA. Because this proposal outlines the use of GPA as a covariate in the analysis of the effect of instructional format on students’ final course grades, careful attention will be paid to the missing GPA records in the data set. A review of missing GPA data by condition and the missing rate by group sample size are presented in Table 2.

**Table 2**

Table

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Overall, 9 GPA records were missing in the online condition, 13 were missing in the hybrid condition, and 26 were missing in the traditional condition. Follow up steps in the replication study proposed herein will be taken to evaluate whether GPA data was missing at random (MAR). To test patterns of missingness, relevant functions from the R packages sjmisc, mi, DescTools, and VIM, will be used to evaluate whether there are patterns associated with GPA missingness. Then, based on these findings, an appropriate strategy for handling missing records will be implemented.

**Univariate Plots and Descriptive Statistics**

**Figure 1**

*Boxplot of Final Course Grade by Group*

**![Chart, box and whisker chart

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**Figure 2**

*Histograms of Final Course Grade by Group*

![Chart, histogram

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**Figure 3**

*Student Baseline GPA Distribution by Group*

**Chart

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**Figure 4**

*QQ-Plot of Normality for Final Grades*

**![Chart, line chart

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**Table 4**

*Final Grade Descriptive Statistics*

*Table

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**Table 5**

*Student GPA by Group Descriptive Statistics*

*Table

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**Research Questions**

RQ1: The purpose of this project will be to examine the effect of instructional format on student grades. Specifically, I will test whether the type of instructional format that a student received had an effect on their final grade. In addition, since a student’s GPA and course grade are expected to be highly correlated, I will also control for GPA as a covariate in the relationship between instructional format and student grade.

RQ2: The second purpose of this study will be to follow up the initial analysis discussed above by conducting a series of comparisons to examine pairwise differences between instructional formats on final grades. In doing so, my goal is to identify which instructional formats are significantly different from one another with regards to student learning outcomes. Moreover, for those comparisons that are significantly different, I will estimate the predicted difference in students’ final grade by instructional format.

**Statistical Methods**

To address RQ1, I will conduct one-way ANCOVA to estimate the treatment effect of instructional format on students’ final grades while controlling for GPA. Specifically, I will conduct an omnibus test of a one-ANCOVA. To address RQ2, I will conduct follow up pairwise comparisons of group means to determine whether certain instructional formats are significantly different from one another. To control for familywise Type I error rate at α = .05, I will conduct Tukey’s HSD adjusted pairwise comparisons.

**Assumptions**

In order to conduct ANCOVA, I will need to satisfy the general assumptions required for ANOVA (εi iid∼ N(0,σ), and I will also need to satisfy ANCOVA-specific assumptions. First, to test ANOVA assumptions, I will need to i) demonstrate that residuals are normally distributed (Normality), ii) demonstrate that variance is constant across the study groups (Constant Variance), iii) demonstrate that residuals have a mean of zero across all values of focal variables (Linearity), and iv) demonstrate that residuals are mutually independent. To demonstrate that these conditions are satisfied, I will generate boxplots and histograms to visually inspect whether variance is constant across groups and to determine whether the data is normally distributed. In addition, I will also generate a QQ plot to examine whether student grades were normally distributed. Also, given unequal-n in this study, I will use Maxwell et al. (2017)’s rule of thumb for assessing constant variance. Specifically, the rule states that constant variance can be established if the product of the ratio of the largest subgroup to the smallest and the ratio of the largest variance to the smallest is less than four. Finally, for a statistical test of constant variance, I will also calculate Levene’s test for homogeneity of variances. The assumption of independence has been satisfied through the random assignment of participants to groups.

In addition to checking for ANOVA assumptions, I will also need to satisfy two ANCOVA-specific assumptions, a) homogeneity of regression slope, and b) that the assumption that the covariate and dependent variable are linearly related. To test for homogeneity of regression slopes, I will generate a scatter plot and fit the regression line estimated by GPA for each group. The scatter plot with fitted lines will then be visually inspected to determine whether the regression lines are parallel. I will follow up this visual inspection of homogeneity of regression slopes by conducting a statistical analysis of regression heterogeneity. Specifically, I will estimate an interaction term in the ANCOVA model and inspect whether the interaction term is significant. The term should not be significant in order to demonstrate heterogeneity of regression slopes. Finally, to test for a linear relationship between the covariate and the outcome variable, I will visually inspect the aforementioned scatterplot to evaluate whether the covariate and outcome are linearly related at every level of the outcome variable across each of the three study groups. In addition, I will calculate the correlation between the covariate and the outcome to demonstrate that the relationship between the covariate and the outcome is large enough (*r* ≥ .30 ) to account for substantial variance explained in the ANCOVA model, demonstrating suitability for a covariate.

References

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**Appendix A**

Online Resources

R code, data visualizations, and a data set for this replication study can be accessed via the publicly-available GitHub repository below:

<https://github.com/gzlupko/5123_Linear_Models/tree/main/Online_Learning_Study>

The data from Alpert et al. (2016)’s A Randomized Assessment of Online Learning was originally accessed online at Open ICPSR at the following URL:

<https://www.openicpsr.org/openicpsr/project/113462/version/V1/view>