Combating the Negative Exam Score Impact of Online Human Physiology Laboratories via Cognitive and Structural Strategies: A Preliminary Analysis

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Abstract: The COVID-19 pandemic forced higher education to develop new strategies to meet the needs of students. One of the most critical issues was delivering an online experience in undergraduate Biology laboratories aimed at meeting hands-on outcomes, specifically within the health sciences. Hybrid lab group models in which students rotated between in-person and online attendance represented one such option. A student population of 71 at Minnesota State University, Mankato was studied to observe the effects on student exam scores. Negative student perceptions were made clear in course feedback surveys, and students that attended 2+ labs via Zoom preceding an exam were associated with a lower Exam I score compared to peers that only attended 0-1 labs via Zoom. Three class strategies were introduced before Exam II, meant to improve online learning. The Exam II scores saw no overall significant difference between groups, with Multi-Zoom students closing the gap from Exam I. Importantly, Multi-Zoom students that utilized the class strategies significantly outperformed Multi-Zoom students that that did not use them. Although any classroom results represent a mix of variables, the risks of online labs intended to assess hands-on and data interpretation outcomes of Human Physiology can be detrimental when targeted strategies are absent.

Keywords: Hybrid, Online, Physiology, Lab, Students, Pre-health

Introduction

The emergence of COVID-19 in 2020 demanded new strategies for a return to higher education institutions ("COVID-19: 20 Countries' Higher Education Intra-Period Digital Pedagogy Responses" 2020). While many educators favored a fully online approach, others adapted a hybrid (FlexSync, HyFlex) method. This challenge was felt particularly hard by the life sciences, as most laboratory sections require students to demonstrate hands-on outcomes to succeed. This is extremely true for the health sciences. Classes such as Anatomy, Physiology, and Microbiology are especially important for success as a healthcare professional since they represent students' first opportunity to collect and analyze physiological data. Human Physiology courses are typically enriched for student pursuing a career in the health sciences, although a more diverse array continues to join the population (Griff 2016). The key conceptual outcomes from lab include Homeostasis, Cellular Physiology (Diffusion and Osmosis), Action Potential, Skeletal Muscle, Cardiac Muscle, White and Red Blood Cells, Lung Physiology, and Kidney Physiology. Moreover, these classes are typically some of the largest on a campus with 10,000+ enrolled students. Meeting the demands of a large student population and COVID-19 space guidelines represents a unique challenge. Another downfall of hybridized, online learning is that the majority of students do not prefer this classroom approach (Adnan 2020). Students cite the lack of hands-on experience and classroom connection as factors. The typical challenges of teaching were exacerbated by a slew of new factors. However, these poor perspectives are not reflected in other primary literature documenting the success of virtual laboratories (Mahaffey 2018; Brinson 2015; Lombardi et al. 2014). Specifically, students cite that the use of structured, asynchronous modules helped keep them on track and improved their experience (Lima et al. 2020). It would appear that exchanging in-person opportunities for a hybridized schedule where students occasionally attend online should only be made when supported by targeted learning structures. This appears especially true for Organismal Biology laboratories that involve gathering live heath data from participants or animal tissues, as is done in Human Physiology.

The contents of this report focus on the effects of online participation in 3 hybridized Human Physiology laboratory sections at Minnesota State University, Mankato. A hybrid approach was utilized in BIOL 330 Human Physiology to facilitate laboratory sections of 24 students to fit in a room with capacity for 16 due to COVID-19 regulations. The lab curriculum was reflective of a typical Human Physiology course (Supplemental Table 2). Lab partner groups of 3 were randomly designated at the beginning of the semester, resulting in 8 groups per section. Each week, 1 member would attend lab via Zoom and 2 would attend in-person. The lab member designated for Zoom would rotate each week. Each group would complete and restart the cycle every 3 weeks.

The hybrid approach facilitated 3 primary benefits. First, labs composed of 24 students could meet COVID-19 space regulations. Second, students that were sick or exposed had a means to attend lab with the online structures in place. Lastly, in-person students received a higher percentage of instructor attention, allowing for unique in-depth learning opportunities. However, the detriment of this structure was clear, with the primary downfalls felt most by students attending online. These pitfalls included technology issues, lack of teamwork/communication, managing the hybrid schedule, and the obvious loss of hands-on learning, the final being most impactful since most labs relied on live experiments or animal tissues. The report herein seeks to document the effects of a hybrid approach on student lab

exam scores, analyze the results by levels of online participation, and highlight steps for the future.

Materials and Methods

Study Population and Data Collection

A total of 71 Human Physiology student exam scores were included in this study, from a course of 253 enrolled students. The 71-student population within this study was divided between 3 laboratory sections. All 3 lab sections followed the same hybrid protocol. One additional lab section of 21 student exam scores were used as a supplemental cohort, and these students were attending a lab with the same hybrid protocols. The population of 71 was split into 3 lab sections – two sections of 24, and one section of 23. 3 students dropped between Exam I and Exam II, reducing the Exam II population to 68. All students received the same study resources, which include access to professors, practice exam questions, guiding questions, their lab notebooks, and lab instruction. The only difference between section exams was the order of questions. Some student took advantage of more resources than others, specifically utilizing professor office hours to discuss guiding questions, but these variables do not represent isolatable categories. Composition of student majors are shown in Figure 1A, and integrated data is available in Supplementary Table 1. Data was collected with course feedback surveys, tracked use of learning platform resources, and examination results – all non-identifying information.

Data Collection

Student majors were documented through the student portal system. Post-exam course feedback surveys were administered to students and were optional with consent. Some students did not complete these. In-person vs. online attendance was tracked by typical attendance procedures. Online participants that chose not to turn on their camera were encouraged to do so. If an online student did not respond to multiple inquiries, they were considered absent from that point and did not receive credit for the lab. These regulations were built into the course to adhere to COVID spacing regulations. Exam scores were collected from the course learning system.

Hybrid Schedule and Normal vs. Multi-Zoom Designation

A typical student schedule would only have a student attend 1 lab via Zoom per every 3 weeks. Each group member would rotate weekly. However, students were required to utilize Zoom in case of sickness or quarantine (likewise, this meant that their lab partners were consequently eligible to attend more in-person labs). At times, this resulted in a student attending more than the planned numbers of labs via Zoom. These students were classified as Multi-Zoom. Any student that attended 2-3 of the first 3 labs via Zoom preceding Exam I was classified as Multi-Zoom, and any student that attended 2-4 of the 4 labs preceding Exam II was classified as Multi-Zoom. Any student that attended 0-1 labs via Zoom preceding Exam I or II was classified as normal. Students were not permitted to Zoom for the sake of convenience.

Laboratory Examination Format and Scoring

Lab exam scores were utilized as a measurement of student success. Exams were based on lab learning outcomes, reinforced with guiding questions at the beginning of each section in the lab notebook. The questions are based on a mixture of laboratory concepts, data interpretation, and application to clinical situations. Both exams were comprised of 100% multiple-choice questions that totaled 75 points. The course total was 825 points, so the 2 exams analyzed in this manuscript represent 18.1% of the course grade. Correct answers earned 100% of a questions value while wrong answers earned 0%. Exam I covered content from 3 labs across 18 questions. Exam II covered content from 4 labs across 24 questions. Each exam was completed in 50 minutes or less. Scoring statistics and information can be found in Table 1. All students marked that enough time was allotted for each exam, and none failed to finish or failed to attempt any questions. Exam format statistics, concepts tested, and example questions can be found in Supplementary Table 2.

Classroom Structure and Cognitive Learning Strategies

The primary strategies were introduced to labs with the intention of closing the gap between normal and Multi-Zoom students (Supp. Table 3). First, Zoom cameras were to be turned on to increase engagement. Second, groups were instructed to work together to create a plan for lab and designate roles, including for the Zoom participant. For instance, one member could be the subject of the experiment, another member could run the data collection program, and the Zoom partner could read along instructions and identify how they related to assignment questions. Lastly, those who participated over Zoom were highly encouraged to fill out a short cognitive reflection survey administered through Microsoft Forms. These strategies were created with the intention of increasing engagement, teamwork, and reflection (Coulson and Harvey 2013; Huitt, Killins, and Brooks 2015).

Statistical Analysis

For the identification of statistical trends between categorical groups of students, raw and percentage test scores were measured. GraphPad Prism software and GenePattern tools were used to plot and format figures, analyze data, and calculate statistical significance (Reich et al. 2006). Comparison of quantitative data between two groups was done by Welch's t-test or a Brown-Forsythe ANOVA test (Table 1) if multiple groups were measured. Parts of a whole statistics were evaluated with Expected vs. Observed analyses, with the null expected ratios being 50/50. When an additional 21 students from another lab section were added to the 71-student cohort to generate a larger study population, all 92 student Exam I scores were normalized to unified Z-score metric and measured. The Welch's t-test comparing these groups used this normalized Z-score value in favor of raw exam scores to correct for the different exam. All reported P values were two-sided. P values less than 0.05 were considered statistically significant. All student data can be found in Supplementary Table 1 and is available upon request.

Results

Student Population and Exam Landscape

The population and course structure were representative of large, non-R1 university Human Physiology courses. There was an enrichment of nursing majors within the population (Figure 1A). The hybrid format – 1 week on Zoom for every 2 weeks in-person – was not well-received by students, with a

substantial 82.5% of respondents indicating that joining a hands-on Human Physiology lab through Zoom had a negative impact on their learning (63/71 feedback responses submitted) (Figure 1B). These results represented a significant difference from the expected 50/50 null hypothesis if students had no clear preference ($P < 0.0001$).

Laboratory exams were utilized as a metric of student success. Exam statistics and student success are presented in Table 1. Notably, Exam II saw a significant reduction in scores from Exam I (Figure 1C), dropping by an average of 16%. Exam I covered 3 labs of material, and Exam II covered 4 (Supplemental Table 2). The difference between Exam I and Exam II was calculated for each student, a measurement of their growth, and data was normalized when noted to account for the 16% decline.

Attending Multiple Labs Over Zoom was Associated with Lower Exam I Scores

The vast majority of the 71 students indicated that attending lab via Zoom was detrimental (Figure 1B). These perspectives were reinforced by the results of Exam I, which documented a lower exam score for those that had to attend 2-3 of the 3 assessed labs via Zoom (Multi-Zoom) vs students that only had to attend 0-1 via Zoom (Figure 2: Normal). Data from an additional lab section of 21 students following the same hybrid protocol was collected and similarly categorized for Zoom frequency. Combined analysis of the 92 normalized student Z-scores reinforced the possible disadvantage faced by Multi-Zoom students (Figure 2) ($P = 0.052$). A Z-score difference of -0.160 ± 0.079 points existed between the groups. Notably, there was a 0.317 Z-score difference in Quartile 1 (25th percentile) between the two groups. No specific questions were enriched for poor responses in the Multi-Zoom group after multiple t-test FDR-corrected analysis with GenePattern Marker Analysis (Supplemental Figure 1).

Classroom Changes were Associated with Lessened Impact of Multiple Online Labs

A set of class changes were implemented after Exam I due to the lower scores of Multi-Zoom students (Supplemental Table3). These were intended to help students before Exam II, which was larger and more thorough since concepts from 4 lab periods were being assessed. Exam II nonetheless proved significantly more difficult than Exam I (Table 1). As an additional measure of student understanding, the difference between Exam I and Exam II % score was measured. The class average was a 16% drop. Notably, having 4 labs preceding Exam II caused an increase in students that had to attend 2 or more via Zoom. Exam II had 27 Multi-Zoom students, an increase from the 12 on Exam I. Whether the Multi-Zoom group made up ground or the normal group lost it, the scores between both groups were remarkably similar (52.78 vs. 51.56; $P = 0.6931$) (Figure 3A). The gap that existed between these groups on Exam I did not emerge in Exam II. For normal vs. Multi-Zoom groups, Quartile 1 (60.5 vs. 63.0) and Quartile 2 (both 53) remained very similar between groups, and a lower Quartile 3 was once again present in the Multi-Zoom group (40 points vs 49.5 in the normal group). One caveat is that 3 of the 71 students dropped the course before Exam II. These students scored an average of 34/75 (45.3%) on Exam I, and all 3 represented Multi-Zoom individuals. The difference in % between Exam I and II was also used as a metric of success, and normal vs. Multi-Zoom students did not produce a significantly different result (Figure 3B). Neither normal (-17.43%) or Multi-Zoom students (-13.71%) were significantly divergent from the class average decline of -16.0%.

The 27 Exam II Multi-Zoom students were isolated to study patterns of improvement. Of these 27 students, 16 (59.3%) chose to utilize the cognitive strategies suggested after the Exam I gap was found (Supplemental Table 3).

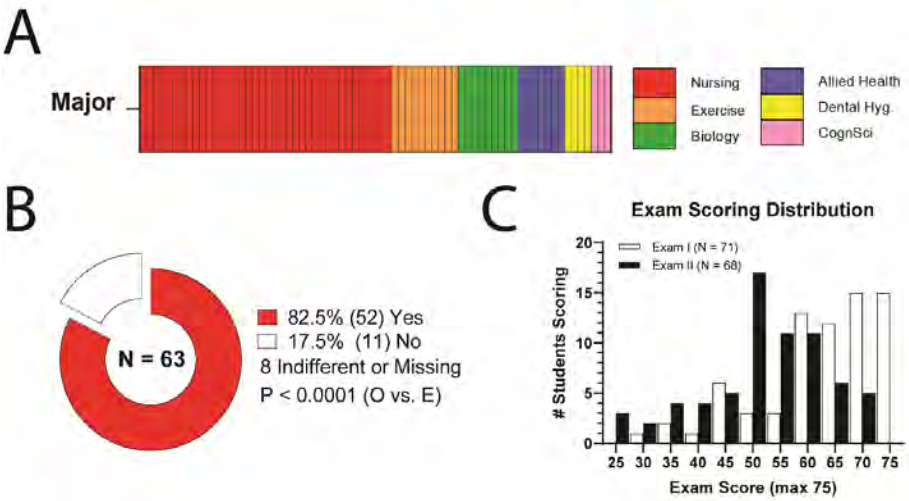

Figure 1: Student Population and Exam Statistics. The study population is comprised of 3 laboratory sections of Human Physiology assessed across 2 exams. (A) Student majors are summarized in a waterfall plot. A single student equals a single column. A color legend designates majors. (B) Proportions of student responses to the question "Does attending lab over Zoom negatively impact your learning?". The results are reported in a pie graph and analyzed for significance with an Observed vs. Expected analysis, which assumes a null hypothesis of 50/50 preference. (C) Exam I and II score distributions are represented by a histogram. Raw exam scores out of 75 points are reported. Exam points and the difference between Exam I and II (in %) were used as a measure of student success.

Table 1. Human Physiology Exam Characteristics

	Exam I (N = 71)	Exam II (N = 68)	P-value
# Questions	18	24	
Points	75	75	
Time	50 minutes	50 minutes	
Labs Assessed	3	4	
Score Average	63.0 (84.0%)	51.6 (68.8%)	< 0.0001*
Score Standard Deviation	11.3 (15.1%)	11.4 (15.2%)	0.907*
Quartile 1	58 (77.3%)	44.5 (59.3%)	0.584†
Quartile 2 (median)	67 (89.3%)	52 (69.3%)	
Quartile 3	71 (94.7%)	61 (81.3%)	
Minimum	29 (38.7%)	25 (33.3%)	
Maximum	75 (100%)	71 (94.7%)	
Range	46 (61.3%)	46 (61.3%)	

* Unpaired t test
† 2-way ANOVA

Table 1. Statistical Comparison of BIOL 330 Human Physiology Lab Exams. Cumulative data was collected from students in all 3 sections to be analyzed together. All sections were led by the same instructor, aimed to meet the same outcomes, and were assessed with the same exams. Exam I occurred on week 4 of the semester and Exam II occurred on week 9 of the semester. Labs did not meet on weeks with a lecture exam.

Multi-Zoom students that utilized the strategies significantly outperformed their counterparts that didn't, scoring an additional 11.87 ± 4.77 points (15.8% ± 6.36%) (P = 0.0266) (Figure 3C). Interestingly, Multi-Zoom students that utilized the strategies (N = 16; 55.69) had a higher point average than normal students (N = 41; 52.78), although this result was not statistically significant

When the difference in % grade between Exam I and II (example: 70% - 65% = -5%) is used as the success metric, there is still a significantly large difference between Multi-Zoom students that used the strategies (-8.08%) between those that didn't (-22.06%) (P = 0.0098) (Figure 3D). These groups were polar between the class average of -16% difference. A dot plot visualizes these rates of decline, with strategy users marked in green and non-users in grey (Figure 3E). These results display students that started with a high Exam I score and declined sharply on Exam II vs those that experienced more stable declines (or in some cases rises). Lastly, Exam II data was divided into 4 groups based on 2 designations: Normal vs. Multi-Zoom and Cognitive Strategies Used vs. Unused and analyzed using a Brown-Forsythe ANOVA test. Although the Multi-Zoom + Strategies Used group displayed the highest average, the overall results were not significant (P = 0.0826) (Supplemental Figure 2). Only 3 students were designated as Multi-Zoom for both Exam I and II. These students did not reflect any statistical trends. In contrast, 35 students were normal participants for both Exam I and II, but again, these students did not display a statistically significant advantage in terms of averaged Exam I/II score. Interestingly, the 11 students that marked that Zoom does not inhibit their learning (Figure 1B) dropped an average of 21.3% between Exam I and Exam II, more than the class average 16.0% drop. Only 5 of these 11 students had been on multiple Zooms for either Exam I or Exam II.

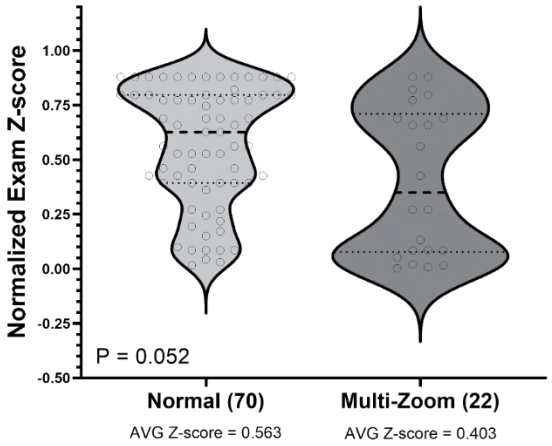

Figure 2: Students that Attended Multiple Labs Over Zoom were Non-significantly Associated with Lower Exam I Scores. Exam I scores are used as a measurement of student success (75 points). Three labs worth of material were tested on Exam I, so students were designated as Multi-Zoom if they attended 2 or 3 of these online. An additional 21 students from one additional section were added to the population, with all 92 scores normalized to Z-scores. These scores are used as the metric between normal and Multi-Zoom students, each represented by a clear bubble. Violin plots demonstrate the population differences and Exam I Z-score values between normal (cyan) and Multi-Zoom (red) students. Clear bubbles represent raw student exam scores out of 75 points. Large, dashed lines within each group represent the average. Small, dashed lines represent Quartile 1 (lower) and 3 (upper) ranges. Differences were measured using a Welch's t-test.

Discussion

Performing hands-on laboratories intended to prepare students for hands-on health science fields over an online

platform was expected to come with negative consequences. This was bolstered by low student opinions of hybrid lab models. The main issues cited in class discussions included alack of hands-on experience with material, insufficient inclusion by in-person partners, and the ability for students to ignore/miss important concepts due to the online format. This report measured the statistical differences in terms of laboratory exam performance, as these exams were intended to measure outcomes associated with patient and tissue data and its interpretation. We are the first to report that while a trend towards poorer exam performance was observed, it can be somewhat mitigated through the implementation of targeted class structures and cognitive strategies.

This report followed a representative group of students in a Human Physiology course during the fall of 2020 at Minnesota State University, Mankato. During the COVID-19 pandemic, hybrid models were utilized to facilitate large enrollment courses, including laboratories. Attending via online platforms was predictably disdained by a large percentage of students. The resources do not exist for many high-enrollment schools to host 100% in-person labs given COVID-19 regulations, so the ability to participate in labs via Zoom proved vital for keeping students connected, especially when they had to quarantine. Altogether, while Zoom was not perfect, it was a much better solution than static approaches, despite student wishes for a full in-person lab experience.

The results of Exam I demonstrated the detrimental effect of attending too many of the labs via the online Zoom platform, with a nearly significant gap emerging between students that attended 0-1 of the labs via Zoom (normal) vs those that had to attend 2-3 of the labs (Multi-Zoom) online. While this result was suspected, it had yet to be observed in a controlled setting with a large number of students. Several Multi-Zoom students informally expressed concern preceding the exam, admitting that in-person experiences were their preferred method of learning.

While it is unscientific to speculate, it should be noted that several students within the cohort cited repeated but variable impasses that prevented them from attending scheduled in-person labs, often unrelated to COVID. Given the supportive structure necessary to maintain class throughout the pandemic, these online attendances were allowed, as well as when absolutely any indication of sickness or contact was cited. Students were also not strongly encouraged to participate online with cameras on during the first 3 weeks, so the effects of attending via Zoom but not being present behind the camera could have exacerbated the detriment. Circumstances aside, the data aligns with student and faculty perspectives that hands-on, Organismal Biology laboratories conducted over an online platform do not predict success on assessments. Virtual labs in place of hands-on counterparts have been observed to meet learning outcome criteria, but these results indicate that traditional labs may still have more to offer most healthcare-oriented students (Hensen et. al., 2020).

Given the steep fall between groups, new strategies were highly encouraged for all 3 lab sections. Although these steps were simple, they represented evidence-based strategies that could buoy learning despite the circumstances

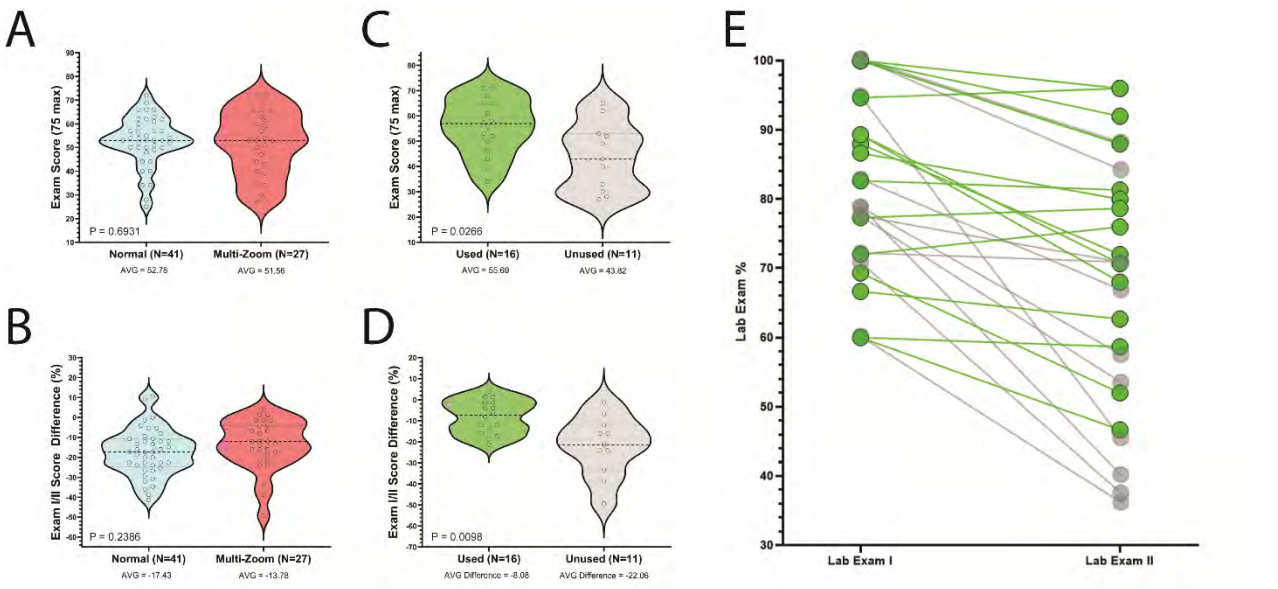

Figure 3: Higher Multi-Zoom Exam II Scores are Associated with Utilization of Classroom Strategies. Three classroom cognitive strategies were introduced to the class after the trend between normal and Multi-Zoom students emerged. (A) Violin plots demonstrate the Exam II scoring differences between normal (cyan) and Multi-Zoom (red) students. Each clear bubble represents a raw student exam score out of 75. Large, dashed lines within each group represent the average. Small, dashed lines represent Quartile 1 (lower) and 3 (upper) ranges. Differences were measured using a Welch's t-test. (B) Violin plots demonstrate the difference in score (%) between Exam I and Exam II. (C) Raw Exam II scores are measured between Multi-Zoom students that utilized the cognitive strategies (green) vs. those that did not (grey). Quartiles and average are displayed similarly between A and B. (D) The difference between Exam I and II scores (in %) are measured between Multi-Zoom students that utilized the cognitive strategies (green) vs. those that did not (grey). (E) A dot plot displays the movement in Exam score (%) between Exam I and II of the 27 Multi-Zoom students. Those that used the cognitive strategies are displayed green. Those that did not are displayed grey.

(Supp. Table 3). Other classrooms have found success implementing similar strategies in STEM (Peng et al. 2020; Villanueva et al. 2020). Exam II assessed concepts from 4 laboratories, so the exam itself was larger, more comprehensive, and caused more of the class to attend 2+ labs online due to the alternating 3-week rotation schedule. The results of Exam II showed a marked improvement for students that attended multiple Zooms, with the performance gap closing. The overall class average decreased significantly though, most likely due to the added content.

Because the Multi-Zoom group erased their deficit in Exam II, factors for success were examined. Among the factors was the use of the cognitive strategies mentioned above, which students marked "Used" or Unused" on the survey questions after Exam II. The data made it very clear: Multi-Zoom that utilized the strategies earned a significantly larger number of raw points and saw a superior average difference in the Exam I to II % scores. Those that used Zoom for multiple labs preceding Exam II and did not decide to utilize the strategies were associated with a significantly lower point total and average difference between Exam I and II, earning lower than class average marks in both categories. Although the strategies were shown to likely influence a more positive outcome, other factors preceding Exam II need to be accounted for. For instance, 3 of the 71 students dropped the course before Exam II. All 3 were Multi-Zoom for Exam I. Additionally, it makes sense that more prepared students would take the time to read and utilize the cognitive strategies, hence why that Multi-Zoom group may have done better no matter what. The other factor is that students may have acclimated better towards the online format. Teamwork likely improved between partners as well, but equally, other groups may have worsened, all depending on context. That said, confounding factors associated with the reporting of these data remain caveats that require consideration.

This work provides an exploratory statistical evaluation of the performance of hybrid classroom approaches for hands-on Human Physiology laboratories. While obvious weaknesses to the approach exist, with some modifications to the group/class structure, some of the detriment incurred by online participation can be remedied. As the COVID-19 pandemic subsides in the future, the hybrid laboratory approach may still carve out a refined role at larger institutions looking to engage more students.

Authors' Contributions

KTH was responsible for collecting data, and analyzing data, creating figures, and authoring the manuscript. Dr. Michael Minicozzi and Dr. Brittany Smith are acknowledged for their contributions of data sharing and supportive consultation, respectively.

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Disclosure of Conflicts of Interest

The are no conflicts of interest to report.

Availability of Data and Materials

All data generated or analyzed during this study are included in this published article [and its supplementary information files]. Requests for additional data may be sent to the author.

Consent Statement

The data herein is archival since it is de-identifiable information that was collected for normal class purposes with the hopes of being used to make beneficial adjustments to the course during the semester.

Ethical Statement

All data collected will remain strictly confidential. All participants were assigned randomized, unique identification numbers used throughout data analysis and reporting. No key linking these identifiers to the students exists.

References

Adnan, Muhammad. 2020. "Online Learning amid the COVID-19 Pandemic: Students Perspectives." Journal of Pedagogical Research. https://doi.org/10.33902/jpsp.2020261309.

Brinson, James R. 2015. "Learning Outcome Achievement in Non-Traditional (Virtual and Remote) versus Traditional (Hands-on) Laboratories: A Review of the Empirical Research." Computers and Education. https://doi.org/10.1016/j.compedu.2015.07.003. Coulson, Debra, & Marina Harvey. 2013. "Scaffolding Student Reflection for Experience-Based Learning: A Framework." Teaching in Higher Education. https://doi.org/10.1080/13562517.2012.752726.

"COVID-19: 20 Countries' Higher Education Intra-Period Digital Pedagogy Responses." 2020. Journal of Applied Learning & Teaching. https://doi.org/10.37074/jalt.2020.3.1.7.

Griff, Edwin R. 2016. "Changing Undergraduate Human Anatomy and Physiology Laboratories: Perspectives from a Large-Enrollment Course." Advances in Physiology Education. https://doi.org/10.1152/advan.00057.2016.

Hensen, Cory, Gosia Glinowiecka-Cox, & Jack Barbera. 2020. "Assessing Differences between Three Virtual General Chemistry Experiments and Similar Hands-On Experiments." Journal of Chemical Education. https://doi.org/10.1021/acs.jchemed.9b00748.

Huitt, Tiffany W., Anita Killins, and William S. Brooks. 2015. "Team-Based Learning in the Gross Anatomy Laboratory Improves Academic Performance and Students' Attitudes toward Teamwork." Anatomical Sciences Education. https://doi.org/10.1002/ase.1460.

Lima, Karine Ramires, Ben Hur Souto das Neves, Caroline Cadore Ramires, Marisele Dos Santos Soares, Victória Ávila Martini, Luiza Freitas Lopes,& Pâmela Billig Mello-Carpes. 2020. "Student Assessment of Online Tools to Foster Engagement during the COVID-19 Quarantine." Advances in Physiology Education. https://doi.org/10.1152/advan.00131.2020.

Lombardi, Sara A., Reimi E. Hicks, Katerina V. Thompson, & Gili Marbach-Ad. 2014. "Are All Hands-on Activities Equally Effective? Effect of Using Plastic Models, Organ Dissections, and Virtual Dissections on Student Learning and Perceptions." American Journal of Physiology - Advances in Physiology Education. https://doi.org/10.1152/advan.00154.2012.

Mahaffey, Angela L. 2018. "Interfacing Virtual and Face-to-Face Teaching Methods in an Undergraduate Human Physiology Course for Health Professions Students." Advances in Physiology Education. https://doi.org/10.1152/advan.00097.2018.

Peng, Peng, Gabriella Reis Barham, William Hunnicutt, Liming Li, & Aaron J. Moment. 2020. "Designing a Hybrid Biopharmaceutical Laboratory Course to Enhance Content Flexibility and Access." Journal of Chemical Education. https://doi.org/10.1021/acs.jchemed.0c00564.

Reich, Michael, Ted Liefeld, Joshua Gould, Jim Lerner, Pablo Tamayo, & Jill P. Mesirov. 2006. "GenePattern 2.0 [2]." Nature Genetics. https://doi.org/10.1038/ng0506-500.

Villanueva, Omar, Derek A. Behmke, J. D. Morris, Rashad Simmons, Chantelle Anfuso, C. M. Woodbridge, & Ying Guo. 2020. "Adapting to the Covid-19 Online Transition: Reflections in a General Chemistry Sequence Taught by Multiple Instructors with Diverse Pedagogies." Journal of Chemical Education. https://doi.org/10.1021/acs.jchemed.0c00752.

Hartert Supplemental Table 1: Population Statistics

Student #	Major	Exam I Points	Exam I %	Multi-Zoom (Exam I)	Zoom bad?	Exam II Points	Exam II %	Exam I/II Difference	MultiZoom (Exam II)	Zoom strats. used	Avg Exam %
1	ALLIED HEALTH	54	72.0	1	1	56	74	2.7	1	1	73.3
2	ALLIED HEALTH	75	100.0	1	0	62	82	-17.3	1	0	91.3
3	NURSING	67	89.3	1	1	50	66	-22.7	1	1	78.0
4	EXERCISE SCI	45	60.0	1	1	43	57	-2.7	0	0	58.7
5	NURSING	75	100.0	1	1	52	69	-30.7	0	1	84.7
6	NURSING	70	93.3	1	0	61	81	-12.0	0	0	87.3
7	NURSING	59	78.7	1	1	27	36	-42.7	0	0	57.3
8	NURSING	71	94.7	1	0	52	69	-25.3	0	1	82.0
9	BIOLOGY	67	89.3	1	1	56	74	-14.7	0	1	82.0
10	EXERCISE SCI	67	89.3	0	1	52	69	-20.0	1	1	79.3
11	NURSING	58	77.3	0	1	58	77	0.0	1	1	77.3
12	NURSING	52	69.3	0	1	39	52	-17.3	1	1	60.7
13	ALLIED HEALTH	50	66.7	0	1	46	61	-5.3	1	1	64.0
14	EXERCISE SCI	62	82.7	0	1	61	81	-1.3	1	1	82.0
15	EXERCISE SCI	58	77.3	0	0	40	53	-24.0	1	0	65.3
16	BIOLOGY	75	100.0	0	1	65	86	-13.3	1	1	93.3
17	NURSING	59	78.7	0	X	43	57	-21.3	1	0	68.0
18	NURSING	62	82.7	0	1	49	65	-17.3	1	0	74.0
19	ALLIED HEALTH	58	77.3	0	X	52	69	-8.0	1	0	73.3
20	BIOLOGY	75	100.0	0	1	65	86	-13.3	1	0	93.3
21	NURSING	66	88.0	0	1	53	70	-17.3	1	1	79.3
22	COGN SCIENCE	53	70.7	0	0	28	37	-33.3	1	0	54.0
23	NURSING	75	100.0	0	1	68	90	-9.3	1	1	95.3
24	COGN SCIENCE	71	94.7	0	X	33	44	-50.7	1	0	69.3
25	NURSING	45	60.0	0	1	43	57	-2.7	1	1	58.7
26	NURSING	71	94.7	0	1	71	94	0.0	1	1	94.7
27	DENTAL HYGIE	75	100.0	0	1	65	86	-13.3	1	1	93.3
28	NURSING	45	60.0	0	1	27	36	-24.0	1	0	48.0
29	NURSING	59	78.7	0	1	30	40	-38.7	1	0	59.3
30	ALLIED HEALTH	65	86.7	0	1	59	78	-8.0	1	1	82.7
31	EXERCISE SCI	45	60.0	0	1	34	45	-14.7	1	1	52.7
32	BIOLOGY	75	100.0	0	1	71	94	-5.3	1	1	97.3

33	NURSING	54	72.0	0	X	53	70	-1.3	1	0	71.3
34	NURSING	75	100.0	0	1	52	69	-30.7	0	1	84.7
35	NURSING	62	82.7	0	1	51	68	-14.7	0	1	75.3
36	NURSING	63	84.0	0	1	62	82	-1.3	0	0	83.3
37	BIOLOGY	70	93.3	0	0	49	65	-28.0	0	0	79.3
38	NURSING	70	93.3	0	0	65	86	-6.7	0	0	90.0
39	EXERCISE SCI	71	94.7	0	X	56	74	-20.0	0	0	84.7
40	NURSING	67	89.3	0	1	53	70	-18.7	0	0	80.0
41	NURSING	63	84.0	0	1	34	45	-38.7	0	1	64.7
42	DENTAL HYGIE	75	100.0	0	1	68	90	-9.3	0	1	95.3
43	ALLIED HEALTH	45	60.0	0	1	33	44	-16.0	0	1	52.0
44	ALLIED HEALTH	75	100.0	0	1	71	94	-5.3	0	1	97.3
45	EXERCISE SCI	41	54.7	0	1	49	65	10.7	0	0	60.0
46	BIOLOGY	75	100.0	0	0	65	86	-13.3	0	0	93.3
47	EXERCISE SCI	75	100.0	0	1	59	78	-21.3	0	1	89.3
48	NURSING	71	94.7	0	0	52	69	-25.3	0	0	82.0
49	NURSING	59	78.7	0	0	40	53	-25.3	0	0	66.0
50	BIOLOGY	62	82.7	0	1	50	66	-16.0	0	1	74.7
51	NURSING	71	94.7	0	1	61	81	-13.3	0	0	88.0
52	DENTAL HYGIE	71	94.7	0	1	56	74	-20.0	0	1	84.7
53	NURSING	71	94.7	0	0	53	70	-24.0	0	0	82.7
54	BIOLOGY	58	77.3	0	1	49	65	-12.0	0	0	71.3
55	EXERCISE SCI	70	93.3	0	1	56	74	-18.7	0	0	84.0
56	EXERCISE SCI	67	89.3	0	1	50	66	-22.7	0	0	78.0
57	NURSING	67	89.3	0	1	40	53	-36.0	0	1	71.3
58	NURSING	46	61.3	0	1	52	69	8.0	0	1	65.3
59	NURSING	75	100.0	0	1	61	81	-18.7	0	0	90.7
60	NURSING	49	65.3	0	1	25	33	-32.0	0	0	49.3
61	BIOLOGY	70	93.3	0	1	65	86	-6.7	0	0	90.0
62	COGN SCIENCE	70	93.3	0	1	61	81	-12.0	0	0	87.3
63	NURSING	58	77.3	0	1	50	66	-10.7	0	0	72.0
64	NURSING	66	88.0	0	1	53	70	-17.3	0	0	79.3
65	NURSING	65	86.7	0	1	48	64	-22.7	0	1	75.3
66	NURSING	75	100.0	0	1	55	73	-26.7	0	1	86.7
67	NURSING	70	93.3	0	1	44	58	-34.7	0	0	76.0
68	DENTAL HYGIE	75	100.0	0	1	58	77	-22.7	0	1	88.7
69	NURSING	36	48.0	1	X	X	X	X	X	X	X
70	NURSING	37	49.3	1	X	X	X	X	X	X	X
71	NURSING	29	38.7	1	X	X	X	X	X	X	X

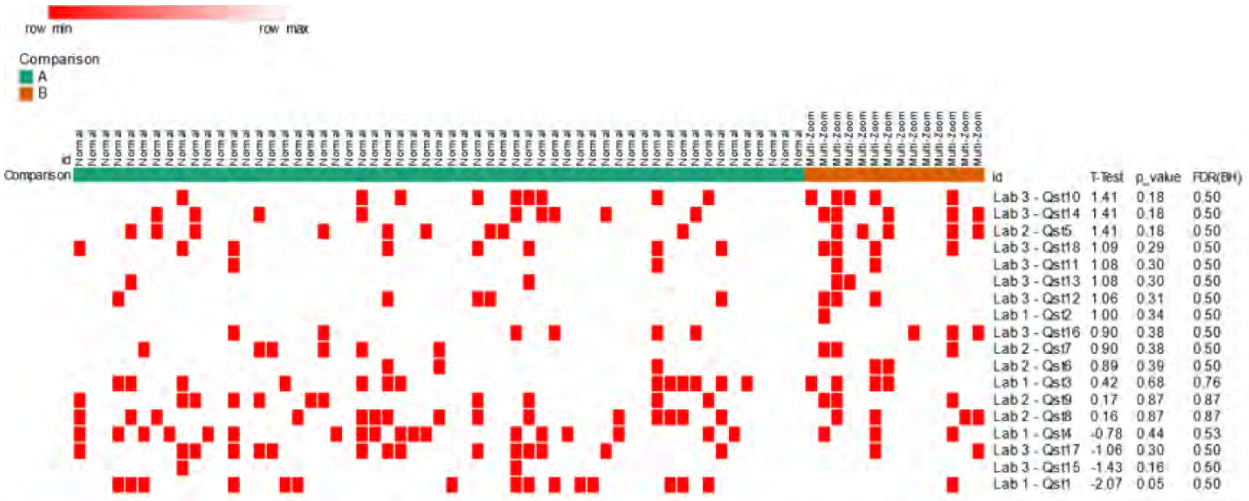
Hartert: Supplemental Table 2: Exam Content

Lab #	Concepts	Exam
1	Homeostasis, Feedback	I
2	Diffusion, Osmosis, Transport	I
3	Action Potential	I
4	Electromyogram (muscles intro)	II
5	Skeletal Muscle (frog muscle)	II
6	Cardiac Muscle (turtle heart demo)	II
7	Electrocardiogram	II
8	Red and White Blood Cells, Immunology	III
9	Lung Volumes	III
10	Kidney (online)	III
	Question Examples	
	Exam I: (5 points) You measure a patient's heart rate and record these readings in BPM: 62, 64, 62, 60, 68, 64. What is the setpoint of this patient's heart rate, and what is their range?	
	A. 63.3 BPM setpoint, 4 BPM range	
	B. 63.3 BPM setpoint, 8 BPM range	
	C. 68.0 BPM setpoint, 4 BPM range	
	D. 68.0 BPM setpoint, 8 BPM range	
	Exam I: (4 points) A sub-threshold stimulus to a single neuron's axon will produce which of the following?	
	A. Due to recruitment, a small action potential will be produced	
	B. Since threshold was not reached, no action potential will be produced (neurons are all or nothing)	
	C. Since action potentials are graded, a very weak stimulus will produce a very small action potential	
	D. A and C	
	Exam II: (3 points) In terms of skeletal muscle cell contraction, which of the following statements is NOT true?	
	A. Myosin forms cross-bridges with actin	
	B. Ca++ enters the muscle cell from the motor neuron	
	C. The muscle cell shortens during contraction	
	D. Myosin is a "motor" protein	
	E. Tropomyosin covers the myosin binding sites on actin	
	Exam II: (4 points) Which of the following do skeletal and cardiac muscle have in common?	
	A. Both experience summation	
	B. Both experience the length tension relationship	
	C. Both experience variable recruitment	
	D. Both can increase contractility	
	Exam II: You would expect the S-T segment to shift during a heart attack because:	
	A. The AV node becomes diseased	
	B. Blood is pumped more slowly	
	C. An ectopic source has taken over the heart rate	
	D. Ventricle tachycardia	
	E. The damaged area slows electrical conduction through the ventricle	

Hartert: Supplemental Table 3: Cognitive Strategies

New Zoom Strategies for Exam II				
1) Cameras on				
2) Designate roles for each group member, involve Zoom member				
3) After Zooming, fill out the cognitive reflection form:				
	Top 3 concepts you learned			
	Top concept you are unclear with and need to work on			
	How to apply concepts from today to your future field			
	Comments and at least 1 direct question for instructor			

Hartert: Supplemental Figure 1: Question Statistics



Supplemental Figure 1. No Specific Questions from Exam I Were Enriched for Either Normal or Multi-Zoom Students. A Marker Selection test was used to detect if questions from Exam I were associated with incorrect (red) or correct (white) responses from Normal or Multi-Zoom students. Questions are identified by number and what lab they assessed. T-tests were conducted for each question. P and FDR values for each question represent the likelihood of association. No significant relationships were observed.