Effects of different delivery modes on teaching biomedical science practical skills in higher education during the 2021 pandemic measures

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Abstract
The COVID-19 pandemic related measures had augmented the rise of online education. While online teaching had mitigated the negative impacts from educational institutional closures, it was unable to displace hands-on biomedical laboratory practical lessons effectively. Without practical sessions, there was concern over the imparting of laboratory skills even with video demonstrations. To investigate the effectiveness of different delivery modes in imparting laboratory skills, theoretical and practical student assessments were analyzed alongside an anonymous survey on their motivation and prior experience. The undergraduate students were exposed to (1) instructor-live demonstration; (2) video demonstration or (3) no demonstration prior to the practical test which was a plasmid extraction. Significantly higher mini-prep yields and purity were found for both instructor-live and video demonstrations compared to no demonstration. Comparison with pre-pandemic theoretical assessment performance showed no significant differences despite longer contact hours during pre-pandemic times. Prior lab experience and motivation for selecting the course did not significantly affect student mini-prep yields. In conclusion, our findings suggest that video demonstrations were as effective as instructor-live demonstrations during the pandemic without noticeably compromising the teaching and learning of biomedical laboratory skills.

Keywords
contact hours, lab demonstration, laboratory skills, mini-prep, visual learning

1 | INTRODUCTION

The 2020–22 COVID-19 pandemic lockdown measures adopted by countries worldwide imposed safe distancing, placing limits on physical attendance and even closures to minimize the formation of infection clusters. Attempts for continued education during such measures have pushed teaching online from the traditional physically present classroom teaching with a number of recent studies investigating the efficacy of online learning. In these efforts, the compatibility of online teaching in the science and engineering disciplines was contested where limited hands-on practical experience...
due to restricted access to laboratories\(^5\) can reduce skill acquisition.\(^6\) This was not unexpected when professional scientists, used to the dependence on centralized research infrastructure, struggle to perform experiments during lockdowns. It was during such unusual restrictions that scientists are re-realizing the benefits of decentralizing research\(^7\) as was during the many discoveries made in the past. While adaptations were made in tertiary science and engineering teaching that included mail-in laboratory reagents\(^8\) or virtual laboratory sessions such as remote control labs or video-based labs,\(^5\) it was not surprising that practical training were compromised as was for the professional counterparts. With insufficient laboratory skills and practice, students from the COVID-19 generation may be at a disadvantage compared to others with a “normal” education, hindering their entry into the skilled labor market.\(^2\) Given the evident disruption to practical skill training, a definitive empirical assessment of COVID-19 educational disruption on laboratory skill acquisition was timely.

In a number of countries without complete lockdowns, the imposed restrictions have resulted in shorter laboratory practical sessions with higher teacher-student ratios. Although smaller class sizes are usually beneficial,\(^9\) the potential compensatory effects in shorter sessions have yet been fully explored and studied in laboratory skill acquisition.

Within the measurement of the proficiency of practical skills within biomedical sciences, particularly molecular biology, the routine small-scale column-based plasmid extraction or “mini-prep” is a suitably common test procedure. By following a series of liquid manipulations using nucleic acid binding columns, plasmid DNA could be extracted from a few milliliters of overnight bacteria culture.\(^10\) As a common yet essential procedure in biomedical laboratories, the mini-prep is typically assessed by the plasmid yield and purity. Thus, for our study, we investigated if the yield and purity would be improved with the incorporation of instructor-live or video demonstrations (Hypothesis 1). Next, we examined if students’ theoretical understanding of laboratory methods as determined by three forms of theoretical assessment, comprising of a weekly class participation quiz, mid-term lab report and end-of-course assessment (ECA), correlated with practical skill performance, measured by higher mini-prep yields and purity (Hypothesis 2). Given that prior experience in biological laboratories can translate to better proficiency, we studied the correlation of this parameter with respect to the mini-prep results (Hypothesis 3). Using an informed consent voluntary survey, the motivation of selecting the elective course and satisfaction of the course were also explored with regards to the association with the mini-prep yield and purity (Hypothesis 4). The final hypothesis and investigation parameter was whether the reduction in class size and contact hours during the pandemic significantly affected the students’ academic achievement, as determined by the three forms of theoretical assessment, aforementioned (Hypothesis 5).

2 | MATERIALS AND METHODS

2.1 | Study participants

The study participants were undergraduate students pursuing the bachelor’s degree in Biomedical Engineering from the Singapore University of Social Sciences (SUSS) on a part-time basis. The pre-pandemic cohorts combining 2018 and 2019 module runs comprised of 59 students, while the 2021 cohort during the pandemic was made up of 54 students. Aggregate data of a second-year elective module, “Experimental Biomedical Laboratory Skills,” offered over four Saturday afternoons (more information at https://www.suss.edu.sg/courses/detail/bme261) was used for this study. The student’s study guide is available at https://ibookstore.suss.edu.sg/pages/ internal/bkstoreLogin.jsf. Course assessments were weekly quizzes based on the material covered at each laboratory session, a mid-term lab report consisting of a mixture of true/false and open-ended questions, as well as an end-of-course assessment (ECA) comprising of short essay questions involving data analysis of results obtained from the lab sessions and understanding of relevant published research. The study was exempted from Institutional Review Board (IRB) review on grounds that the data were anonymized, non-identifiable, aggregated and were secondary analysis of routine academic assessment. Informed consent was obtained for the collection of voluntary and anonymized data pertaining to having prior laboratory experience, motivation of choosing the elective, and satisfaction of the course. The survey questionnaire (Table S1) was administered through APD Psychvey,\(^11,12\) an in-house developed survey tool as part of student satisfaction feedback.

2.2 | Research design

A quasi-experimental design was employed to explore if instructor-live and video demonstrations would help students perform better in the mini-preps. This involved 54 students from the 2021 cohort. The pandemic affected students were divided into three groups of maximum 20 students per group (due to pandemic measure restrictions), taught over three consecutive 4-week runs from mid-January to mid-April 2021. Due to social distancing rules imposed during the pandemic, the students were
further subdivided into groups of 10, with one group having had their 2.5-h laboratory sessions from 1200 to 1430 h, and the other from 1530 to 1800 h on the respective Saturdays. All sessions were led by the same instructor with one or two teaching assistants. The shortening of the laboratory contact hours (i.e., compared to 5-h weekly during pre-pandemic years 2018 and 2019 with a total enrolment of 59 students) did not compromise the overall course learning outcomes as laboratory activities such as laboratory briefings and theoretical explanations were provided in the form of online videos for students to view prior to their physical attendance. The videos were recorded Zoom® sessions sharing the screen displaying the relevant sections of the study guide and YouTube® links specified in the study guide. The instructor appeared in a smaller screen at the corner of the videos.

The first lesson in each run involved the training and familiarity with micropipettes, and the loading of DNA samples onto agarose gels; the second lesson involved spin-column RNA extraction from HEK293 cells, followed by cDNA synthesis and PCR of the GAPDH housekeeping gene, procedure adapted from previous work,13 as well as spin-column based PCR product clean up using the kit (Catalog BS664, Bio Basic Asia Pacific Pte Ltd., Singapore). The third lesson involved gel electrophoresis and spin-column gel band extraction using the kit (Catalog BS654, Bio Basic Asia Pacific Pte Ltd., Singapore), followed by ligation and transformation to CaCl2 competent cells adapted from14 for teaching. The fourth and final lesson was the practical test where the students were provided the protocol sheet for the mini-prep using the kit (Catalog BS614, Bio Basic Asia Pacific Pte Ltd., Singapore) with the intervention of (1) instructor-live demonstration of the mini-prep procedure by a skilled teaching assistant; (2) video demonstration of the procedure in close-up (shown in https://youtu.be/69qSF3fL1Po and also screenshots in Figure S1); and (3) no instructor-live or video demonstration. For consistency with instructor-live demonstration, the video was shown once prior to the test and projected on a screen for the students. Regardless of the mode of demonstration, all students were given a verbal briefing of the protocol prior to the test to ensure that no groups would be disadvantaged, (evidence of no significant overall impact in Table S2).

All students extracted the original pET21d plasmid (Invitrogen, Singapore) from in-house competent Escherichia coli DH5α strain, grown in Luria-Bertani broth supplemented with 100 μg/ml of ampicillin, cultured at 37°C, 250 rpm for 15 h before each run. At the final step of the mini-prep procedure, they eluted the plasmid in 30 μl of elution buffer before the yield and purity were measured using the Nanodrop1000 Spectrophotometer (ThermoFisher Scientific, Singapore) and a mobile spectrophotometer.15,16 The mini-prep yield concentration in ng/μl and purity by A260/280 were the parameters for analysis. To rule out undetected influences, mini-prep of each run sample was also performed in parallel by the skilled teaching assistant alongside the students in each session. Across the internal references, an average mini-prep yield of 100 ng/μl was achieved, with an A260/280 ranging between 1.93 and 2.08.

### 2.3 | Statistical analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS) version 27 (SPSS, Inc.). A Shapiro–Wilk Test of normality determined some of the data variables were non-parametric (p < 0.05). Therefore, using a conservative approach, non-parametric tests of the data were performed using Mann–Whitney U, Kruskal–Wallis, and the Chi-square (χ²) test, depending on the data type (continuous, ordinal, nominal) to be analyzed. Kruskal–Wallis test of independent variables were used for parameters with more than two groups, whereas the Dunn’s test was used for post hoc between groups. Differences between median values were set at 95% confidence interval (p < 0.05). Effect sizes were calculated using formulas previously.17 Additional data organization and statistical elaborations are provided below. As some of the data were not normal distributed, median was used instead of means that were also shown in supplementary for easy reference.

In testing hypothesis one, the purity was determined by the A260/280 values and classified into the ideal range (1.7–2.0) and non-ideal (>2.0)18 before χ² analysis. Besides performing a Spearman correlation to test hypothesis two, mini-prep yields were categorized into intervals of 25, specifically, 0.0–25.0, 25.1–50.0, 50.1–75.0, 75.1–100.0, 100.1–125.0, 125.1–150.0 and >150.0 ng/μl for the Kruskal–Wallis analysis. Since the students’ mini-prep yields contributed to a portion of their assessment scores, these scores were excluded to obtain a more accurate analysis for Hypothesis 2. A similar exclusion was done for Hypothesis 5 for theoretical assessment only to ensure comparability of the data from the pre-pandemic and during pandemic cohorts to minimize differences. For testing Hypothesis 4, open-ended responses were thematically coded by two independent researchers and semi-quantified. To reduce the amplification of the plasmid extraction impact on the analysis of the theoretical assessments, the scores for the component were removed prior to statistical analysis even though the practical test component was not found to impact student grades individually.
3 RESULTS AND DISCUSSION

This research aims to study the effects of instructor-live, video, and no demonstration on plasmid extraction in an undergraduate molecular biology class during pandemic-associated restrictions, as well as the impact of their use on teaching practical skills for biomedical sciences.

**Hypothesis 1.** There would be significant difference in mini-prep yield and $A_{260/280}$ purity obtained by students with instructor-live or video demonstration compared to no demonstration of the mini-prep procedure.

Undergraduate students of the 2021 pandemic cohorts had instructor-live, video or no demonstration prior to a mini-prep procedural test, where mini-prep yield and $A_{260/280}$ data was collected. Given that the data was non-parametric, the Kruskal–Wallis test showed a statistically significant difference ($p < 0.01$) in mini-prep yield across the three groups with a small effect size of $\chi^2(2, N=54) = 12.424, p = 0.002, \eta_p^2 = 0.226$. Post hoc Dunn’s test with Bonferroni adjustments (Table 1) showed significantly higher median mini-prep yields for instructor-live ($p < 0.01$) and video demonstrations ($p < 0.01$), respectively. Box plots of mini-prep yield (Figure 1a) showed no significant difference in the median mini-prep yield between instructor-live and video demonstrations.

With regards to mini-prep purity $A_{260/280}$ ratio assessment where $<1.7$ and $>2.0$ is indicative of RNA contamination and protein contamination respectively, the mini-prep purity obtained by the students were categorized into ideal (1.7–2.0) and non-ideal (>2.0) before a $\chi^2$ test of association was performed across the demonstration groups. The $\chi^2$ test showed a significantly large association between mini-prep purity and the demonstration groups at $\chi^2(2) = 30.390, p < 0.001, \phi_c = 0.750$ (Table 2). Kruskal–Wallis test using $A_{260/280}$ ratios as a continuous variable re-affirmed the significant difference in plasmid purity between the demonstration groups with a moderate effect size at $\chi^2(2, N=54) = 29.552, p < 0.001, \eta_p^2 = 0.537$. A post hoc Dunn’s test with Bonferroni adjustments (Table 3) showed significantly lower median mini-prep $A_{260/280}$ ratios for instructor-live ($p < 0.01$) and video demonstration ($p < 0.05$) within the ideal range.

**TABLE 1** Mini-prep yields pairwise comparisons using Dunn’s test among study groups

| Study groups                | n  | Median mini-prep yield (ng/μl) | Comparing with no demonstration | Comparing with video demonstration |
|-----------------------------|----|-------------------------------|---------------------------------|-----------------------------------|
| Instructor-live Demonstration | 20 | 86.3                          | Adjusted $p$-value: 0.008*       | $H$-value: 15.314                  |
| Video Demonstration         | 16 | 79.7                          | Adjusted $p$-value: 0.006*       | $H$-value: 16.764                  |
| No Demonstration            | 18 | 40.8                          |                                  |                                   |

*Significant at $p < 0.01$ (2-tailed).

**FIGURE 1** Box plot of mini-prep yield and purity among study groups.

*Significant at $p < 0.05$ (2-tailed) and **significant at $p < 0.01$ (2-tailed)
compared to no demonstration. Boxplots of the mini-prep yield (Figure 1b) showed the median $A_{260/280}$ ratios for no demonstration to be 2.12 in the non-ideal range (Table 3). The absence of prior demonstration (live or recorded) did not protect the students from procedural mistakes that could increase RNA contamination. Since no student had an $A_{260/280}$ ratio below 1.70, the mini-prep kit was shown to be relatively fool-proof to protein contamination. There was no significant difference in the median of mini-prep $A_{260/280}$ purity between instructor-live and video demonstration cohorts.

Hypothesis 2. The students’ theoretical understanding determined by a total score derived from the weighted scores of class participation quizzes, mid-term lab report and end-of-course assessment (without the practical test contribution) were positively associated with mini-prep yield and $A_{260/280}$ purity. Since the students’ mini-prep yields contributed to a portion of their assessment scores (the ECA), this was first removed from the total score for more accurate analyses. Spearman correlation test of the mini-prep yield and students’ scores in the three different modes of assessment (based on a continuous scale) showed only a statistically negative correlation for mid-term lab report scores ($p < 0.05$, see Table 4). No significant correlation was found between class participation quizzes, ECA and expectedly the total scores, given that the class participation quizzes and ECA constituted to 70% of the final total score (Class participation quizzes, mid-term lab report and ECA). As for the relationship between purity ($A_{260/280}$) and assessment scores, a degree of monotonicity violation was present where purity was affected after exceeding a certain upper and lower limit (Figure 2).
Since no student recorded an $A_{260/280}$ ratio below the lower limit, we proceeded with the Spearman correlation test on the assumption that increasing $A_{260/280}$ values correlated with lower assessment scores. Nonetheless, no significant correlations were found from this analysis (Table 4).

**TABLE 4** Spearman correlations between scores of different assessment modes and mini-prep yield, and $A_{260/280}$ purity where $N = 54$

| Type of assessment | Class participation quiz (10%) | Mid-term lab report (20%) | End-of course assessment (70%) | Total (10%) |
|--------------------|--------------------------------|--------------------------|-------------------------------|-------------|
| Mini-prep yield    | Correlation Coefficient        | $-0.120$                 | $-0.332^*$                    | $0.003$     | $-0.055$ |
| Sig. (2-tailed)    | 0.387                          | 0.014                    | 0.980                         | 0.692       |
| $A_{260/280}$ purity | Correlation Coefficient        | 0.100                    | 0.081                         | $-0.159$    | $-0.127$ |
| Sig. (2-tailed)    | 0.471                          | 0.563                    | 0.252                         | 0.361       |

*Significant at $p < 0.05$ (2-tailed).

**FIGURE 2** Box plot of assessment scores across mini-prep yield ranges. *Significant at $p < 0.05$ (2-tailed)
Additional Kruskal–Wallis tests were performed to better understand the significant negative correlation found between mini-prep yield and mid-term lab report scores. Mini-prep yields were categorized based on their ranges and compared to the various assessment scores. The Kruskal–Wallis test showed that lower performances in the mid-term lab report were associated with higher mini-prep yields. This association was statistically significant with a small effect size, at \( \chi^2 (6, N = 54) = 14.729, p < 0.05, E_R = 0.267 \) to which the underlying reasons remained elusive. A post hoc Dunn’s test with Bonferroni adjustments showed that students with higher mini-prep yields (>150 ng/\( \mu \)) scored lower (\( Mdn = 66.0\% \), \( M = 64.8\%, SD = 8.51 \)) for their mid-term lab report than those with a lower plasmid yield of 50.1 to 75.0 ng/\( \mu \) (\( Mdn = 78.0\%, M = 77.3\%, SD = 6.18 \)) There was no significant difference between other assessment scores and the mini-prep yield ranges.

Hypothesis 2 assumed that good acquisition theoretical knowledge determined by cumulative scores from different assessment components would translate into better acquisition of practical skills measured by increased mini-prep yield and purity. Since there were no significant positive mini-prep differences in relation to the three modes of assessment, strong theoretical knowledge did not play a role in improving mini-prep purity, likely due to the robustness of the extraction kit. Hypothesis 2 was thus rejected noting an interesting significant negative correlation and significant measure of median difference between the mid-term lab report score and the mini-prep yield. Since the mid-term lab report was to be submitted on the night of the final practical laboratory lesson, a plausible reason could be that higher mini-prep yield obtained led to some form of complacency into completing the report. The absence of any significant correlation between the mini-prep yield with the ECA and total score could also be due to the two-week gap between the mini-prep practical test and the ECA submission date. The results here thus show that practical test performance was largely independent of the theoretical assessments with the implication on the commonly reported disconnect between industry expectations of practical performance and tertiary academic training. In such independence of performances, there may be reason for future separation of practical and theoretical modes of assessments and course planning.

Hypothesis 3. Prior laboratory experience, class timings, awareness of study topic, and appreciation of the elective course were positively associated with mini-prep yield and \( A_{260/280} \) purity obtained.

In testing Hypothesis 3, an informed consent, anonymized, voluntary survey querying the prior experience, appreciation of the topic and motivation/satisfaction was conducted to complement whether the timing (early or late afternoon sessions) and appreciation of the elective course had any effect on their mini-prep results. With a response rate of 74% obtained voluntarily from the students, a Mann–Whitney \( U \) test (Table 5) demonstrated no significant difference in median mini-prep yields with these parameters. Likewise, a \( \chi^2 \) test showed no association between mini-prep \( A_{260/280} \) purity and prior laboratory experience (\( \chi^2 \) \( [1] = 0.312, p = 0.576 \)), class timings (\( \chi^2 \) \( [1] = 0.277, p = 0.599 \)), awareness and appreciation of ethics involved in molecular technology (\( \chi^2 \) \( [1] = 0.494, p = 0.482 \)) as well as the factor of appreciating and understanding challenges and timelines involved in diagnostic kits and their usage in drug development (\( \chi^2 \) \( [1] = 294, p = 0.588 \)). With no positive association of these parameters with mini-prep yield and \( A_{260/280} \) purity, Hypothesis 3 was thus rejected.

Prior laboratory experiences were initially perceived as beneficial in facilitating the acquisition of new laboratory skills. In the absence of any association between

| Potential factors                                      | Category | Median mini-prep yield (ng/\( \mu \)) | \( p \)-Value | Significantly different |
|--------------------------------------------------------|----------|--------------------------------------|--------------|------------------------|
| Prior laboratory experience                            | Yes      | 79.7                                 | 0.628        | No                     |
|                                                        | No       | 80.5                                 |              |                        |
| Afternoon Session                                      | Early    | 70.9                                 | 0.972        | No                     |
|                                                        | Late     | 64.3                                 |              |                        |
| More awareness and appreciation of ethics involved in molecular technology | Yes      | 79.7                                 | 0.25         | No                     |
|                                                        | No       | 241.0                                |              |                        |
| Appreciation and understanding of challenges and timelines involved in diagnostic kits and their usage in drug development | Yes      | 81.1                                 | 0.051        | No                     |
|                                                        | No       | 40.3                                 |              |                        |
prior laboratory experiences with mini-prep yield and purity, it should be noted that the inherent limitation of this study utilizing only mini-prep may not fully reflect the repertoire present in prior experiences that could range from biochemistry to analytical or physics-based skills. Class timings did not seem to pose an issue to the final learning outcomes of the students, suggesting the emphasis to be more on individual factors. Meanwhile, the awareness and appreciation of ethics involved in molecular technology as well as appreciating and understanding the challenges in development of diagnostic kits and drugs, did not translate to better mini-prep extractions. On a more positive note, 39 out of 40 students, and 38 out of 40 students indicated a “Yes” for the two questions respectively, implying that the instructor had successfully communicated the relevance of the module to the COVID-19 pandemic. This form of teaching where current relevance was incorporated into discipline-specific lessons has been demonstrated to be beneficial to students in gaining global competence, and was opportunistic with the ongoing pandemic diagnostic kits which utilized the practical principles taught in the course. Nonetheless, the education industry may note that in this case, the perceived applicability of the course material could not be discerned from the academic performance.

**Hypothesis 4.** Student motivation to take the elective course can positively affect mini-prep yield and $A_{260/280}$ purity.

In testing Hypothesis 4, students’ responses ($n = 37$) to the survey questions on their reason of choice for taking the course were coded into thematic areas. It was thought that students with clear goals and intentions of taking the elective course may strive harder in acquiring basic laboratory skills that would translate to better mini-prep yields and purity. Four key themes emerged: “Interest in laboratory work,” “Intention to gain laboratory experience,” “Course sounded interesting” and “Others.” Students classified under the “others” category included two students who took the course because they mistakenly thought it to be a core compulsory module; 1 student wanted to “follow a friend,” and another felt “it was an easy course.” The $\chi^2$ test using the cross tabulation (Table 6), showed no significant associations between the various reasons for taking the course with respect to the mini-prep yields, $\chi^2 (3, N = 37) = 4.015, p = 0.26$. Likewise, there were no associations between the various reasons for taking the course with respect to the mini-prep purity cross tabulated in Table 7, $\chi^2 (3, N = 37) = 3.899, p = 0.273$. With no associations between the various reasons for taking the course and mini-prep yield or purity, Hypothesis 4 was thus rejected, noting that motivation did not necessarily translate to practical performance.

**Hypothesis 5.** The decrease in class size and reduced contact hours for biomedical laboratory would make a difference in student theoretical assessment.

| Table 6 | Mini-prep yield range $\chi^2$ test cross tabulation among different reasons of taking the course |
|---------|--------------------------------------------------------------------------------------------------|
|         | Mini-prep yield range (ng/µl) | Reasons in themes | Interest in laboratory work | To gain lab experience | Sounds interesting | Others | Total |
|         |                                 | N   | %  | N   | %  | N   | %  | N   | %  | N   | %  | N   | %  |
| <100.0  |                                 | 8   | 61.5 | 5a  | 83.3 | 10  | 71.4 | 1a  | 25.0 | 24  | 64.9 |
| >100.0  |                                 | 5a  | 38.5 | 1a  | 16.7 | 4   | 28.6 | 3a  | 75.0 | 13  | 35.1 |
| Total   |                                 | 13  | 100.0 | 6   | 100.0 | 14  | 100.0 | 4a  | 100.0 | 37  | 100.0 |

*a*6 cells (75.0%) have expected count less than 5. The minimum expected count is 1.41.

| Table 7 | Mini-prep yield purity $\chi^2$ test cross tabulation among different reasons of taking the course |
|---------|--------------------------------------------------------------------------------------------------|
|         | Mini- $A_{260/280}$ | Reasons in themes | Interest in laboratory work | To gain lab experience | Sounds interesting | Others | Total |
| Ideal (1.7–2.0) | 7 | 53.8 | 5 | 83.3 | 12 | 85.7 | 3 | 75.0 | 27 | 73.0 |
| Non-ideal >2.0 | 6 | 46.2 | 1 | 16.7 | 2 | 14.3 | 1 | 25.9 | 10 | 27.0 |
| Total | 13 | 100.0 | 6 | 100.0 | 14 | 100.0 | 4 | 100.0 | 37 | 100.0 |
In testing Hypothesis 5, students’ aggregate academic results of the theoretical components from three pre-pandemic course runs (two runs in 2019 and one in 2018, total $n = 59$) were compared with the three course runs during the pandemic year 2021 ($n = 54$). To normalize the results of both pre-pandemic and during pandemic runs for comparison and without amplification of the mini-prep contribution, the practical test component was excluded in the analysis. A Mann–Whitney $U$ test showed significant difference in the median of class participation quiz scores with a large effect size ($U = 355, p < 0.001, r^2 = 0.671$), between pre-pandemic and during pandemic course runs. The aggregated median score was 86.7% and 77.8% with higher scores during pre-pandemic times. Accompanying mean and standard deviations, conventional of most educational studies where normal distribution was found or assumed are provided in Table 8. This difference may be attributed to reduced contact hours in the laboratory although this will require investigations. In contrast, the Mann–Whitney $U$ test showed significantly lower mid-term lab report scores pre-pandemic ($Mdn = 59.0$) as compared to during the pandemic ($Mdn = 71.5$) with a moderate effect size ($U = 2492.5, p < 0.001, r^2 = 0.487$). Analysis where plasmid yield scores were reflected, found in Table S2, showed similar trends. It may be likely that students access to online instructional materials allowed them to learn concepts more thoroughly on their own, leading to better lab report scores. It should be noted that the practical scores did not affect the individual grades of the students with regards to passing or failure or grade bands. Coincidentally, the aggregated median scores for the ECA pre-pandemic and during the pandemic were identical at 48.5. This served as evidence to show that reduced class sizes and reduced physical contact hours did not have an obvious impact on overall theoretical assessment performance of the students. Given that the ECA contributed to 70% of the total score, there were expectedly no significant difference in the median total score between pre-pandemic and during pandemic runs. Considering that pre-pandemic mini-prep data was not retrievable during the preparation of this manuscript and that the procedure set-up was different, the effect of reduced class sizes and reduced physical contact hours on practical performance cannot be assessed conclusively as a limitation in our study.

Although decreasing the class size by half and reduced contact hours led to significant differences in mid-term lab report scores, the impact on total score was marginal given their much lower weightage (20%). There was no significant difference in total scores and in this module, the smaller class size and reduction in contact hours led to no observable or immediate impact on students’ overall academic achievement. This could be due to the compensatory effects of the benefits of halving the class sizes, being canceled out by the reduction in contact hours even when supplemented with online self-learning. Nonetheless, the final Hypothesis 5 was thus rejected.

### CONCLUSIONS

Using plasmid mini-prep as a gauge for biomedical lab proficiency, we found instructor-live and video demonstrations to benefit students learning of practical skills compared to no demonstrations. With the move to online learning, video demonstrations were shown to be effective in teaching practical skills during the pandemic related restrictions. In addition, the reduced contact hours with the briefing moved to pre-recorded videos did not negatively impact student performance compared to pre-pandemic classes, perhaps mitigated to a certain degree by smaller class sizes. There was also no clear association between perceived relevance of the module

| Period             | (10%) class participation quiz /% | (20%) mid-term lab report /% | (70%) end-of-course assessment (ECA)/% | (100%) total score /% |
|--------------------|-----------------------------------|-----------------------------|--------------------------------------|----------------------|
|                    | $Mdn$ | $M$ | $SD$ | $Mdn$ | $M$ | $SD$ | $Mdn$ | $M$ | $SD$ | $Mdn$ | $M$ | $SD$ | $Mdn$ | $M$ | $SD$ |
| Pre-pandemic       | 86.7  | 85.2 | 7.4  | 59.0  | 59.6 | 11.9 | 48.5  | 51.9 | 13.6 | 55.2  | 56.8 | 10.7 |
| During pandemic    | 77.8  | 74.7 | 9.8  | 71.5  | 71.0 | 8.3  | 48.5  | 49.7 | 14.8 | 56.4  | 56.5 | 11.4 |

*Significant at $p < 0.01$ (2-tailed).
content nor motivation with performance, suggesting that it is not often possible to discern other factors from academic performance. Through our comparison with pre-pandemic cohorts, a certain independence between theoretic and practical assessments was also found, with reason for future course design and assessment methods to keep the two modes separate.

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The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT
Dataset used for the study can be shared upon reasonable requests.

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