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Successful Integration of Face-to-Face Bootcamp Lab Courses in a Hybrid Online STEM Program †

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The Microbiology and Cell Science program at the University of Florida compressed two standard 16-week lab courses into five-day versions of the course, which are referred to as bootcamp labs. The bootcamp labs have the same objectives, activities, and assessments as their traditional counterparts. Development of the bootcamp labs was part of a larger effort to increase access to the major, and more broadly STEM, by offering a 2+2 hybrid online transfer program. The results of this mixed-methods study include a direct comparison between bootcamp and traditional lab format as an approach for delivery of a face-to-face lab course. The bootcamp lab cohort has a greater diversity of students, with more women and underrepresented minorities in STEM than the traditional semester-long cohorts. Students in the bootcamp labs have comparable grade outcomes and learning gains to students in traditional lab format. Regression analysis identified GPA, but not lab format, as the most significant predictor of success for students enrolled in lab courses. Qualitative results suggest that the bootcamp format may be a better way than traditional formats to teach microbiology lab. In summary, the results demonstrate that a bootcamp version of a face-to-face microbiology course is just as effective as the traditional semester-long version. This work has broader implications as it supports the bootcamp lab approach as a model in STEM education for increasing access and for overcoming a major barrier to online STEM programs: face-to-face delivery of key lab courses.

INTRODUCTION

Online degree programs in STEM play a role in meeting the national goal of increasing the number and diversity of graduates in STEM (1–3). To expand the reach of its curriculum and broaden participation, the Microbiology and Cell Science (MCB) Department at the University of Florida (UF) developed a 2+2 hybrid online transfer program in 2011. In this paradigm, two-year students transfer into the MCB major via an online track to complete their baccalaureate degree. While the program format provides overall comparable outcomes for the online and on-campus students, delivering a rigorous, yet accessible, face-to-face lab in a primarily online STEM program presents a major challenge (2–4). Innovative strategies are necessary to provide students in online tracks access to the essential face-to-face lab courses required in STEM degree programs. Here, the modification of two traditionally delivered microbiology lab courses into compressed versions is described, hereafter referred to as bootcamp labs. The effectiveness of the bootcamp labs' format is compared with the traditional semester lab format.

While the accessibility of online education has the potential to address education deserts, geography does remain a hindrance in college opportunity (5, 6). For example, in lab courses, which provide physical and practical experiences, delivery to more remote student populations is particularly challenging. In addressing the challenge of teaching the required microbiology labs to students in a primarily online program, there are multiple options and factors to consider.

For an online degree program, virtual labs seem like a natural fit, as they can be effective in the acquisition of conceptual knowledge, affordable, easy to scale, and accessible (7, 8). Alternatively, at-home, or portable, lab kits present another option to accommodate distance students.

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Although previous studies support a role for virtual labs in supplemental learning, there are no data that demonstrate virtual or at-home kit options can serve as replacements for face-to-face labs (9, 10). Furthermore, at this time, there are no known medical schools in the United States that accept completely virtualized lab courses for admissions, which is an important and practical consideration for students and programs (11). However, lab course formats that retain face-to-face teaching and implementation of lab skills and techniques, such as bootcamp labs, do meet face-to-face lab requirements from medical and other professional schools. Thus, implementing a bootcamp lab format was an attractive option because it provides a physical hands-on lab experience, which is important for developing skills and understanding the realistic challenges in a lab, and maintains accessibility and eligibility for medical school and professional programs (7, 8).

Here, a mixed-methods approach is used to test two hypotheses. The first hypothesis is that the bootcamp lab format is as effective as the semester-long version of a required face-to-face microbiology lab as measured by student outcomes. The second hypothesis is that the bootcamp lab format increases accessibility and broadens participation as determined by more diverse student populations compared with the traditional semester-long lab. With over five years of data from the bootcamp format for two required face-to-face microbiology lab courses in an online Bachelor of Science degree program, these results can serve as a model to online STEM educators in implementing and assessing essential lab components. Although immersion, or time-shortened, courses are implemented in different STEM programs and contexts, to date, we are not aware of any study that directly compares bootcamp lab course formats with the traditional semester lab course format. Thus, this research addresses a key gap in STEM education.

METHODS

Participants and data collection

This study compared the enrollment, outcomes, and student responses between delivery formats of the laboratory courses of the MCB major in the College of Agricultural and Life Sciences (CALS) at the University of Florida.

The MCB curriculum requires two lab courses: Principles of Microbiology (PoM) lab and an Advanced Microbiology (AM) lab, the former being a prerequisite for the latter. All analyses of the two lab courses were performed separately since the labs had different instructors, presented different curricula, and used different teaching methodologies. Bootcamp labs were designed to accommodate students in the hybrid online 2+2 transfer program, which began in 2013 and is offered annually. Therefore, students in the bootcamp labs are primarily hybrid online transfer students (MCB-OL), whereas the students in the traditional semester-long format are entirely on-campus students. The on-campus students either began as freshmen (MCB-UF) or transferred (MCB-TR). Enrollment by student type is shown in Table 1. A full list of abbreviations used in the manuscript is provided in Appendix 1.

The MCB major is offered through two different colleges, CALS and the College of Liberal Arts and Sciences. Therefore, students enrolled in the required lab courses may be students of either college. The analysis here is restricted to students in CALS because the hybrid online 2+2 transfer program is only available through CALS. Admission and graduation requirements are different between the colleges, so limiting the analysis to MCB majors in CALS reduces variables and represents a stronger comparison of lab formats.

All program and institutional data were de-identified. This study was approved as exempt by the University of Florida Institutional Review Board (IRB 201601296). The analysis was funded by grants from the NSF: Science and Technology Expansion Program (STEP) (1161177) and Scholarships in STEM (S-STEM) program (1643780). Project funders had no role in the collection, analysis, and interpretation of data and had no role in the final decision to publish the work.

Statistical analyses

Demographic and gender comparisons between the traditional and bootcamp formats were performed using 2×2 contingency tables, and statistical significance was determined using Fisher's exact test. The methodology in Garrison (12) was used to compare proportions of underrepresented minorities (URMs) and non-URMs across lab formats; individuals of three racial and ethnic groups—Hispanic, Black, and American Indian or Alaska Native—are considered URMs in STEM fields.

Student GPAs represent either final GPAs for those who have graduated or most current GPAs for students actively enrolled in the MCB program. Due to the nature of GPAs as a variable (skewed, interval, upper and lower limits), Kruskal-Wallis with post-hoc testing for multiple comparisons using the Tukey and Kramer (Nemenyi) method was applied to compare GPAs of student groups (MCB-UF vs. MCB-TR vs. MCB-OL). The same method was used to compare student age at the time of enrollment between student groups.

To evaluate course grade outcomes, letter grade frequency among lab delivery formats was compared using Fisher's exact test for count data. Ordinal logistic regression analysis (13) was utilized to identify the main predictors of letter grade outcome in laboratory courses. Coefficients and confidence intervals were exponentiated to facilitate interpretation, and p values were calculated by comparing the t value against the standard normal distribution. Plus/minus letter grades were granted to students. However, to simplify analyses, course grades were defined as A (≥90%), B (80%–90%), C (70%–80%), and D-F-W (60%–70%, <60%, or withdrew from the course).

TABLE 1.
Enrollment in traditional and bootcamp formats of Principles of Microbiology lab and Advanced Microbiology lab for Microbiology and Cell Science majors in the College of Agricultural and Life Sciences.

Course	Student Type (ratio)	2011	2012	2013	2014	2015	2016	2017	2018
PoM (*N*=210)	Traditional (UF:TR:OL)	—	—	10 (8:2:0)	17 (8:9:0)	19 (12:7:0)	22 (9:13:0)	25 (18:7:0)	12 (9:3:0)
	Bootcamp (UF:TR:OL)	—	—	4 (0:0:4)	15 (0:0:15)	15 (1:2:12)	20 (2:0:18)	21 (0:1:20)	30 (0:0:30)
AM (*N*=233)	Traditional (UF:TR:OL)	17 (13:4:0)	41 (25:16:0)	32 (22:10:0)	—	—	—	—	—
	Bootcamp (UF:TR:OL)	—	—	10 (2:3:5)	16 (7:7:2)	29 (6:7:16)	29 (1:2:26)	26 (0:0:26)	33 (0:0:33)

Lab course totals (N) represent enrollment observations, not unique student counts.
PoM = Principles of Microbiology; AM = Advanced Microbiology; UF = on-campus students, first-time in college; TR = on-campus transfer students; OL = online transfer students.

Pre- and post-assessments were administered anonymously in the AM lab; therefore, a paired analysis of individual gains could not be assessed. However, the average pre- and average post-assessment scores were calculated for each year, and the difference in the averages is reported as learning gains. Further explanation of the pre- and post-assessments, including the assessment questions, is included in Appendix 2.

For all statistical tests performed, $p < 0.05$ was considered significant. All analyses and data visualizations were performed using R 3.5.0 (14).

Qualitative assessment

Students' perceptions of the quality and effectiveness of the different bootcamp formats were explored through individual and group interviews (15, 16). These interviews were conducted with students who participated in either the PoM lab, the AM lab, or both labs during 2016 or 2018.

A total of nine interview sessions were conducted (6 interviews in 2016 and 3 in 2018), with the participation of 48 students (37 students in 2016 and 11 in 2018). Only 11 of the 48 students were on-campus students; the rest were part of the online MCB program (Appendix 3, Table A3.1). Fewer students participated in an interview focused on just one format; this is a result of the majority of students opting to take both bootcamp labs the same summer.

Interview sessions were audio-recorded to maintain the integrity of the data (17) and were transcribed in preparation for the analysis (17, 18). Coding of the data was followed by thematic analysis to identify similarities, differences, and patterns. The analytical procedure followed the four-step process described by Harding (19), which includes coding the data, identifying categories, and looking for themes and findings within each category to identify similarities, differences, and/or patterns among the cases. In this case, the unit of analysis, or case, is the focus group session.

RESULTS

Design and enrollment

From 2013 to 2018, PoM and AM, two required lab courses for all MCB majors, were offered using a bootcamp delivery format (Fig. 1). Each respective bootcamp lab course was developed and taught by the same instructor all six times. The two instructors also taught traditional semester versions of the lab courses. Students in the online cohort (MCB-OL) have priority registration in the bootcamp labs, but any remaining open spots are available to on-campus, non-transfer majors (MCB-UF) and on-campus transfer majors (MCB-TR). The enrollment in the bootcamp lab courses has climbed steadily but is capped at 36 students (Table 1). From 2013 to 2015, the PoM bootcamp lab was taught in 11 consecutive days. In 2016, the PoM bootcamp lab was condensed again to five consecutive days by integration of an online preparatory module. In the subsequent analyses, the 11- and 5-day hybrid bootcamps are analyzed as separate treatments. Starting in 2016, students were able to take PoM and AM bootcamp lab courses back-to-back.

Regardless of delivery format, the curricula of all PoM labs and all AM labs were unchanged. Principles of Microbiology is typically taken by MCB majors in their third year and AM is taken afterwards in their third or fourth year. Both courses and formats meet the lab course guidelines as outlined in the American Society of Microbiology curriculum guidelines (Appendix 4, Table A4.1) (20).

Demographics of bootcamp and traditional lab students in the Principles of Microbiology labs

Race and ethnicity. The PoM bootcamp labs enrolled a higher proportion of underrepresented minority (URM) students in STEM than the corresponding traditional PoM labs from 2013 to 2018 (Fisher's exact test; $p = 0.049$). From

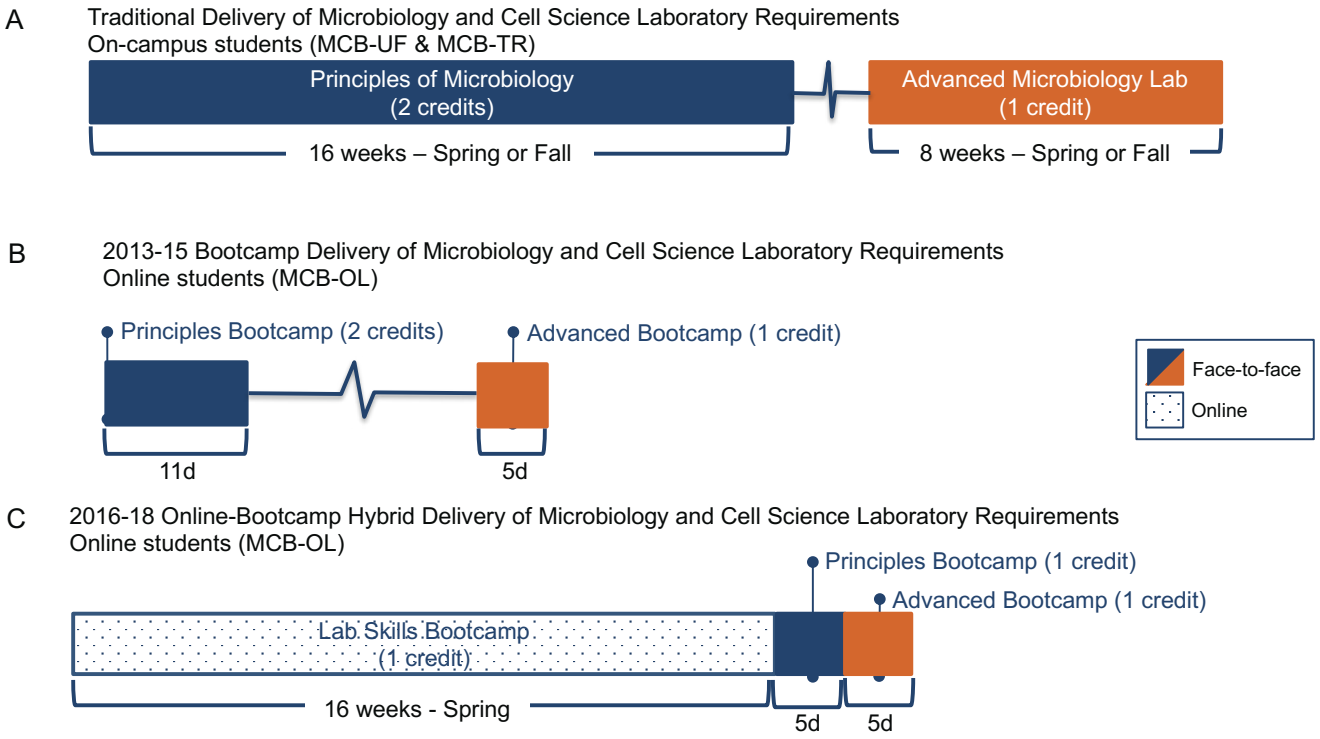

FIGURE 1. Layout of laboratory course requirements of the MCB program. Two lab courses, PoM (2 credits) and AM (1 credit) labs, for a total of three credits, are required for all MCB majors. (A) In the traditional delivery of labs, PoM lab is delivered over a full semester (16 weeks) and meets twice a week, while AM lab (1 credit) also meets twice a week but occurs over half a semester (8 weeks). Therefore, lab requirements are satisfied in 1.5 semesters. (B) In the face-to-face delivery format offered from 2013 to 2015, PoM lab was offered over 11 consecutive days at the end of the summer semester. The five-day AM lab was offered at the beginning of the following summer semester, so lab requirements were satisfied in a total of 16 days with two semesters between the two bootcamp lab courses. (C) In the hybrid delivery format offered from 2016 to 2018, online Lab Skills Bootcamp (1 credit) was offered in the spring semester, followed by a five-day, face-to-face bootcamp lab (1 credit), together satisfying the credits required for PoM lab. The five-day AM bootcamp was offered immediately following the PoM bootcamp, so lab requirements are satisfied in 1 semester and 10 days. MCB = Microbiology and Cell Science; UF = on-campus students, first-time in college; TR = on-campus transfer students; OL = online transfer students; AM = Advanced Microbiology; PoM = Principles of Microbiology.

2013 to 2018, 37.1% (N = 39) of students enrolled in PoM bootcamp labs were URM students compared with 25.0% (N = 26) of students enrolled in the traditional PoM lab (Fig. 2A; Appendix 5, Table A5.1).

The difference in diversity is expected given that the bootcamp cohort consists primarily of students in the online program (MCB-OL), which already has a higher proportion of URM participation (42%) than the corresponding on-campus MCB-UF and MCB-TR programs (27%). For comparison, the institution-wide URM level of undergraduate students is 30%. Furthermore, at the program (MCB-OL; 42%) and course (Bootcamp; 37%) levels, the percentage of students who identified as URM was closer to that of the state of Florida, in which 52.1% of the 18- to 29-year-old population identified as a URM according to the 2017 population estimates (21).

Sex. Bootcamp and traditional formats of PoM lab enrolled a comparable percentage of female students, 66.7% and 62.5%, respectively (Fig. 2B; Fisher's exact test, p = 0.565). As observed in the race and ethnicity data, the percentage of female and male students enrolled in the MCB labs reflected the demographics of their corresponding programs.

At the program level, there was increased representation of female students in the hybrid online program (MCB-OL; 68% female), compared with the on-campus program (MCB-UF+TR; 55% female) (Fisher's exact test, p < 0.001). The percentage of female students enrolled in an on-campus MCB program was representative of university-wide numbers (55% female; Fig. 2B). Therefore, there was increased participation of women in the online program and bootcamp labs compared with the on-campus MCB program and university-wide.

Grade point average. Because previous analyses have shown the GPA of the MCB-UF cohort can be higher than the other cohorts, the mean GPAs of MCB-OL, MCB-TR, and MCB-UF students were compared (2, 3). MCB-UF students enrolled in PoM had greater cumulative GPA than

MCB-OL or MCB-TR students (p = 1e-6 and p = 0.0014, respectively, Kruskal-Wallis test) (Fig. 2C).

Age. The median age of transfer students was higher than their first-time-in-college classmates. This age gap was most pronounced for MCB-OL students, who, with a median age of 26, were on average 6.0 and 7.2 years older than both on-campus student types, MCB-TR and MCB-UF, respectively (p = 1.2e-12 and p = 2.8e-14, respectively, Kruskal-Wallis test) (Fig. 2D).

Academic performance of bootcamp vs. traditional lab formats

To measure the effectiveness of the bootcamp format compared with the traditional lab, overall course grades were compared. In this analysis, the same instructor designed the curriculum and taught all versions of the PoM lab course (Fig. 3A). In both formats, the students' final letter grade was based on a lab practicum, findings and interpretations in a lab notebook, quizzes, and assignments.

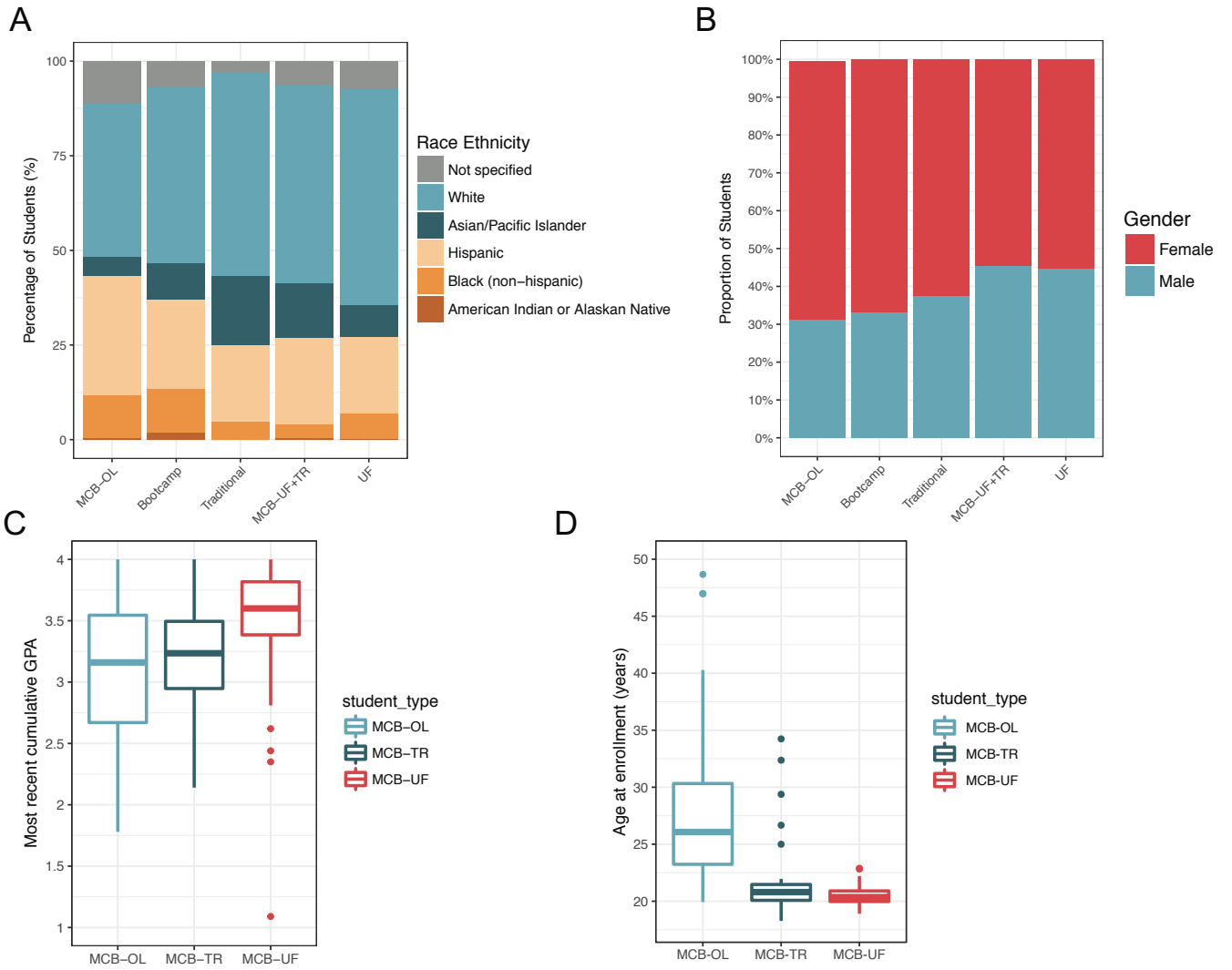

FIGURE 2. Demographics and GPA for PoM lab students. (A) Bootcamp labs hosted more URM students than the traditional lab format (p = 0.049, Fisher's exact test). This was represented at the program level, where MCB-OL students were more diverse than MCB-UF+TR students; the latter being comparable with university-level (UF) demographics. Values represented are average percentages across the observation period, 2013–2018. (B) Bootcamp and traditional lab formats hosted a comparable ratio (2:1) of female-to-male students (p = 0.565, Fisher's exact test), with increased representation of female students in the labs and MCB-OL compared with MCB-UF+TR and university-wide (UF). (C) MCB-UF students enrolled in PoM lab had greater cumulative GPA (p = 1e-6 and p = 0.0014, respectively, Kruskal-Wallis test) than MCB-OL and MCB-TR students. (D) MCB-OL students in PoM lab were on average 6.0 and 7.2 years older at the time of enrollment than MCB-TR (p = 1.2e-12) and MCB-UF students (p = 2.8e-14), respectively (Kruskal-Wallis test). MCB = Microbiology and Cell Science; UF = on-campus students, first-time in college; TR = on-campus transfer students; OL = online transfer students; AM = Advanced Microbiology; PoM = Principles of Microbiology.

The learning objectives were the same and the scope and level of difficulty were equivalent across all iterations and versions of the PoM lab. All students, regardless of delivery format, received the same lab practicals, quizzes, and assignments, with minor alterations to prevent cheating and answer sharing. For example, students were asked to perform the same tasks but encountered a variety of conditions (different bacterial cultures to identify, different reagent concentrations, etc.), ensuring that students understood and were able to apply the fundamentals of different lab skills and enforce deep learning and retention of topics presented.

Principles of Microbiology letter grade frequencies from traditional lab sections (2013–2018), 11-day bootcamp lab sections (2013–2015), and 5-day hybrid bootcamp lab sections (2016–2018) were compared. There was no difference in the frequency of course letter grades (A, B, C, and D/F/W) among traditional labs, bootcamp labs in 2013–2015, and hybrid bootcamp labs in 2016–2017 (Fisher's exact test; $p = 0.907$) (Fig. 3B).

Ordinal regression analysis was performed to determine how different factors including lab format (bootcamp, hybrid bootcamp, or traditional), student type (MCB-UF, MCB-TR, or MCB-OL), sex, URM status, and GPA affected lab course grade outcomes (Table 2). A student's GPA was the best indicator of letter grade earned in PoM lab (proportional odds ratio [OR] = 9.33; $p < 0.001$); that is for each unit increase in GPA, a student was approximately nine times more likely to receive a single letter increase in their course grade. Lab format was not predictive of grade outcome.

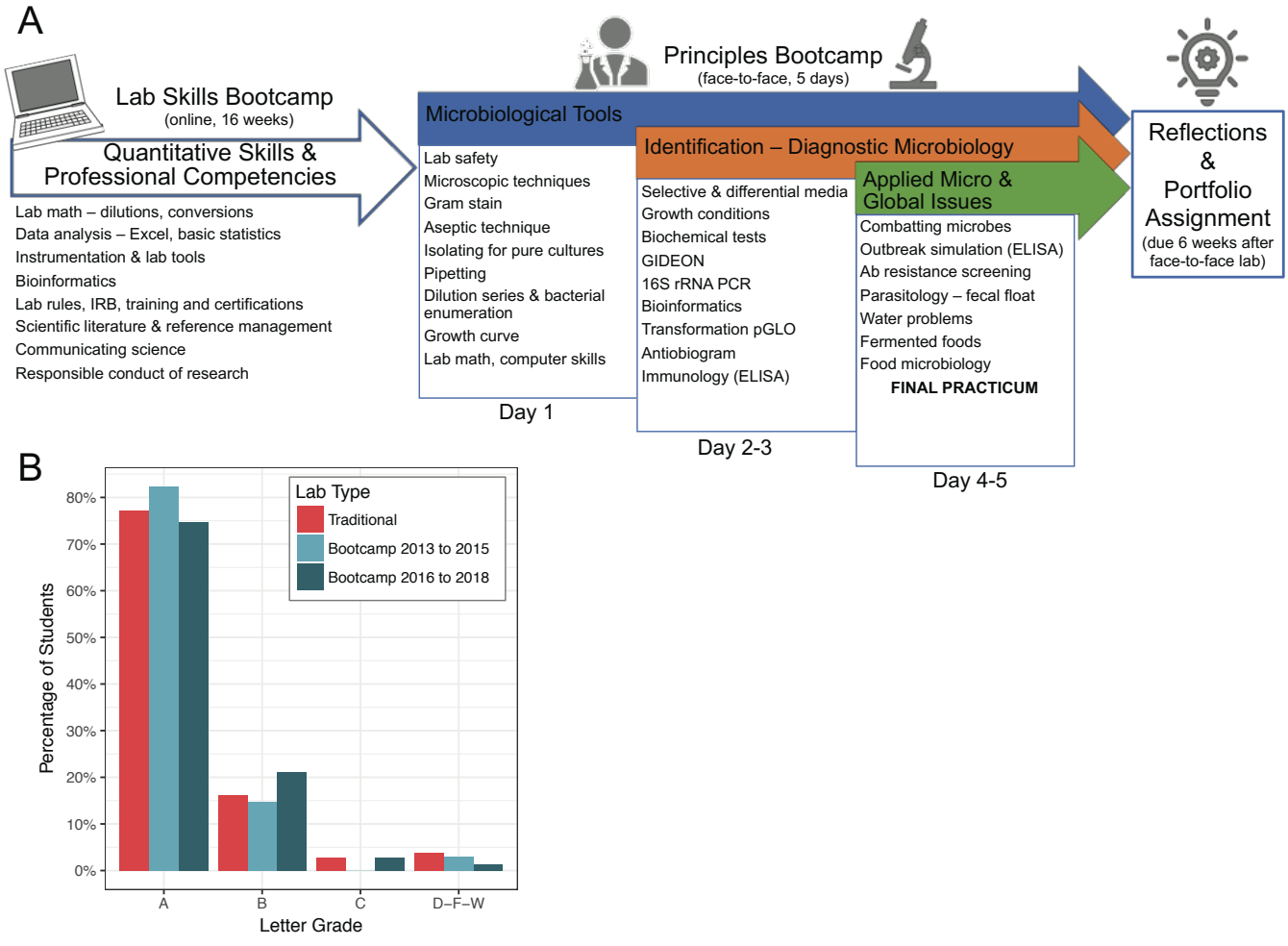

FIGURE 3. Design and grade frequency of PoM lab. (A) In the current PoM hybrid scheme as depicted in Figure 1C, concepts and skills conducive to online delivery are first introduced in the 16-week, online Lab Skills Bootcamp, including quantitative skills, microbiology lab equipment, training, and scientific communication, among other concepts. These concepts are then reinforced and executed during the five-day, face-to-face bootcamp, where students gain hands-on experience in applying them. Mastery of skills is assessed with a final practicum, testing students' ability to successfully perform a series of microbiology lab skills that were taught throughout the sequence. Students then have six weeks to submit a Reflections and Portfolio assignment, which is meant to recap and enforce deep learning and retention of topics learned. (B) Grade frequency for PoM labs. There was no difference in the frequency of letter grades between traditional (N=105) and bootcamp (N=34) labs in 2013–2015 and hybrid bootcamp (N=71) labs in 2016–2018 (Fisher's exact test, $p = 0.907$). PoM = Principles of Microbiology.

TABLE 2.
Ordinal regression results of grade outcome indicators in PoM labs.

Predictor	OR (CI)	*p* value
GPA	9.333 (4.52, 20.8)	<0.001 (7.25e–9)
Lab format:		
Bootcamp 2013–2015	2.44 (0.183, 74.9)	0.546
Bootcamp 2016–2018	1.35 (0.112, 44.7)	0.839
Student type:		
MCB-TR	1.217 (0.435, 3.46)	0.708
MCB-OL	1.272 (0.038, 18.4)	0.877
Gender – Male	0.460 (0.215, 0.97)	0.042
Race – URM	0.685 (0.319, 1.49)	0.333

GPA is the best indicator of letter grade granted in PoM lab, where a one-unit increase in GPA corresponds to a given student being nine times more likely to receive an increased letter grade. Gender was a marginally significant indicator of increased course grade. Lab format, student type, and URM status had no effect on letter grade outcome as indicated by the proportional OR, CI, and p values resulting from ordinal regression analysis. Students of unknown race/ethnicity were excluded (N=199). OR = odds ratio; CI = confidence interval; MCB = Microbiology and Cell Science; TR = on-campus transfer students; OL = online transfer students; URM = under-represented minority.

Concurrent implementation and validation of bootcamp format in Advanced Microbiology lab

As the second required lab for the MCB major, AM lab captures most of the same students as PoM lab. Because both labs were implemented at the same time (2013), albeit by different instructors and with different curricula, AM lab serves as a validation of the hypothesis that bootcamp delivery format of labs is comparable with traditionally formatted labs.

Design—bootcamp format of a CURE. Principles of Microbiology is a prerequisite for AM. Advanced Microbiology uses a course-based undergraduate research experience (CURE) approach (Fig. 4A). Typically, all or most students enrolled in the bootcamp sections of PoM and AM are online transfer students (MCB-OL). However, the AM bootcamp sections taught from 2013 to 2015 were unique because all three student types, on-campus non-transfers, on-campus transfers, and online transfers, were enrolled in sufficient numbers to allow for a direct comparison of grade outcomes by student type.

Demographics. Overall, the demographics of traditional and bootcamp formats of the AM sections mirrored the demographics observed in PoM labs. Advanced Microbiology bootcamp labs had a higher percentage of URM students (39.1%) than traditional format labs (28.7%), but this difference was not significant (Appendix 5, Fig. A5.1A; Fisher's exact test, $p = 0.148$). Likewise, AM bootcamp labs, PoM labs and traditional format labs hosted a comparable number of female students (Appendix 5, Fig. A5.1B; Fisher's exact test, $p = 0.131$). As observed in the PoM lab courses, MCB-UF students had a higher cumulative GPA than MCB-OL and MCB-TR students ($p = 2.6e\text{-}4$ and 3.3e-4, respectively, Kruskal-Wallis test) (Appendix 5, Fig. A5.1C). Finally, MCB-OL students were on average 4.5 and 6.3 years older than their MCB-TR and MCB-UF classmates at the time of enrollment in AM labs ($p = 1.2e\text{-}8$ and 3.3e-14, respectively, Kruskal-Wallis test) (Appendix 5, Fig. A5.1D).

Academic performance. Similar to the results for PoM, there was no difference in the frequency of letter grades (A, B, C, and D/F/W) between traditional and bootcamp labs (2013–2015 or 2016–2017) (Fisher's exact test; $p = 0.133$) (Fig. 4B).

Results from ordinal regression analysis again identified a student's GPA as the strongest indicator of letter grade earned in AM lab (proportional OR = 12.2; $p < 0.001$); that is, for each unit increase in GPA, a student was 12.2 times more likely to receive a single letter increase in their course grade (Table 3). Regression analysis results also indicated that the AM bootcamp lab format 2013–2015 was predictive of grade outcome (proportional OR = 3.22; $p = 0.033$). Thus, students taking the bootcamp format in 2013–2015 were about three times more likely to receive an increased letter grade than students taking bootcamp lab in 2016–2017 or traditional AM lab. However, further analysis indicated that this result was driven by on-campus non-transfer (MCB-UF) students with already high GPAs who enrolled in the bootcamp sections in 2013–2015. Therefore, the 2013–2015 bootcamp format cannot be confidently designated as a predictor of outcome (Appendix 6).

In addition to course grades, pre- and post-learning gains were compared between bootcamp and traditional AM lab. Overall, all cohorts experienced learning gains at similar levels from pre- to post-assessment (Fig. 4C). Average performance for each question on the pre- and post-assessment is provided in Appendix 6, Figure A6.3.

Qualitative findings

Focus groups of MCB-OL students were conducted in 2016 and 2018 immediately upon completion of the bootcamp lab course(s) to assess student perceptions of the bootcamp lab format.

Students found the bootcamp lab experience valuable, particularly citing the hands-on experience that the labs provided. All students agreed that the quality of the online hybrid 2+2 degree program would not be the same without the immersive bootcamp lab course. In addition, students found the online preparatory module completed prior to the immersive component in the five-day hybrid PoM bootcamp to be a good introduction that provided the required context to understand the intensive, face-to-face five-day bootcamp experience.

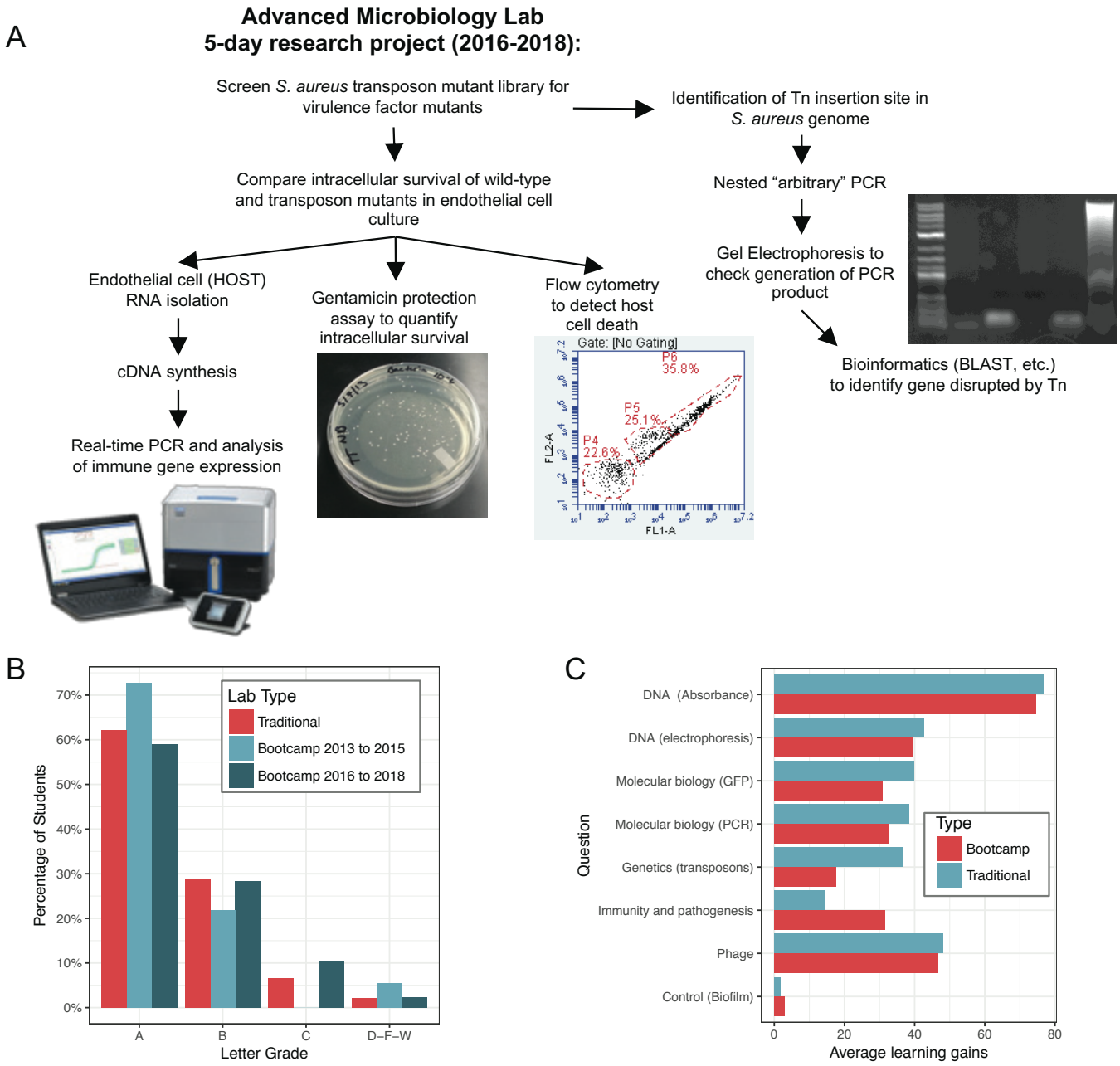

FIGURE 4. Learning outcomes for AM lab. (A) The bootcamp format of the lab is designed as a course-based undergraduate research experience (CURE) and completed in five days. (B) There is no difference in the frequency of letter grades between traditional (N=90) and bootcamp (N=55) labs in 2013–2015 and bootcamp (N=88) labs in 2016–2018 (Fisher's exact test, p = 0.133). (C) Pre- and post-assessment of core concepts showed comparable learning gains for students taking the bootcamp (2013–2015) and traditional (2011–2013) lab formats. Learning gains were calculated by subtracting the average percent correct response of the pre- from the post-assessments. GFP = green fluorescent protein.

When asked how their experience in the bootcamp labs compared with traditional lab courses that they have taken, the students generally agreed that the courses were challenging, mainly due to time constraints. They also felt the bootcamp labs were a better educational experience. In particular, students cited the continuity of the experience and that it teaches teamwork and decision-making that better mimics a real-life scenario. All the students interviewed agreed that the bootcamp format was a better preparation for life and finding a job afterward. Student quotes include, "It's almost like conducting an actual research lab in which you would be working on," and "I've actually learned better with it being so condensed."

In addition, analysis of focus groups reveals that enthusiasm was a major theme among the students. Students said that with the bootcamp lab course being shorter than

TABLE 3.
Ordinal regression results of grade outcome indicators in AM labs.

Predictor	OR (CI)	*p* value
GPA	12.2 (5.97, 26.2)	<0.001 (3.27e–11)
Lab format:		
Bootcamp 2013–2015	3.22 (1.15, 10.1)	0.033
Bootcamp 2016–2018	3.28 (0.864, 13.2)	0.086
Student type:		
MCB-TR	0.495 (0.205,1.18)	0.112
MCB-OL	0.295 (0.072, 1.12)	0.080
Gender – Male	0.943 (0.507, 1.77)	0.852
Race – URM	0.662 (0.356, 1.23)	0.192

GPA is the best indicator of letter grade granted in AM lab. Students taking the bootcamp lab 2013–2015 were more likely to receive a higher letter grade for the course. Student type, gender, and URM status had no effect on letter grade outcome as indicated by the proportional OR, CI, and *p* values resulting from ordinal regression analysis. Lab type considers 2013–2015 and 2016–2018 bootcamp cohorts separately due to a change in course design. Students of unknown race/ethnicity were excluded (*N*=220). OR = odds ratio; CI confidence interval; MCB = Microbiology and Cell Science; TR = on-campus transfer students; OL = online transfer students; URM = under-represented minority.

a regular 16-week semester, it was easier to maintain interest during the entire course and remain motivated from start to finish.

DISCUSSION

This work describes the successful implementation and assessment of time-shortened, bootcamp microbiology lab courses that were developed to overcome the challenge of delivering face-to-face essential labs to students enrolled in a hybrid online STEM degree program. The time-shortened PoM lab course evolved into a hybrid bootcamp format, which blends online delivery of conceptual and quantitative skills to prepare students for an immersive five-day face-to-face lab emphasizing practical skills. Students voiced their preference for a hybrid, bootcamp approach because it maintained their enthusiasm while mimicking real-life work scenarios. These results are in line with the recommendations that a blended delivery format capitalizes on the strengths of online and in-person instruction (7), fosters favorable attitudes toward biology (22), and satisfies the need of today's growing non-traditional student population for flexibility (2, 11).

The AM lab employs a course-based undergraduate research model, which is effective in engaging students and provides a more realistic experience to that of a research and professional setting (23). Furthermore, the student engagement of a CURE can increase graduation rates and completion of STEM degrees (24), which is especially pertinent for transfer students, who characteristically experience lower retention and graduation rates (25).

With a national effort to increase diversity in STEM, online programs are a means of increasing accessibility and reducing opportunity gaps (3). Online programs are also helpful in education deserts, where a higher proportion of the population is of low socioeconomic status (5). The bootcamp lab cohorts were more diverse than traditional lab cohorts, with a higher proportion of underrepresented minority students in STEM and an older student population. The demographics of the bootcamp lab reflect the overall diversity of the MCB online student cohort.

Course grade outcomes are comparable with those of traditional lab delivery format for both PoM and AM bootcamp labs, demonstrating that multiple lab courses can adopt the bootcamp format successfully. Cumulative GPA was the best predictor of course letter grade. Other studies have also found that course performance with different delivery formats is influenced by GPA (26, 27). Meanwhile, regression analysis indicates that delivery format did not affect student outcomes in the PoM lab. Taken together, these quantitative results indicate that the bootcamp format is effective in teaching students microbiology core competencies and lab skills.

Furthermore, qualitative evidence suggests that boot camp lab delivery may be more beneficial than traditional, semester-long labs, particularly in maintaining student motivation and engagement. Previous research has shown that outcomes and student achievement are statistically similar in time-shortened courses to those in semester courses and that students might have higher motivation than in regular courses (28, 29), but this research was limited to lecture courses and did not study lab courses. Because of the different environments of the delivery formats, the way in which students learn and retain skills and concepts in a bootcamp lab may differ from the process in a traditional lab format. A follow-up study is in progress that examines the long-term retention of microbiology skills and concepts in students who participated in the bootcamp versus the traditional lab format. Thus, the quantitative and qualitative results here open new avenues of research into exploring the bootcamp lab learning process.

Innovative approaches are needed to meet the challenges of bringing STEM degree opportunities to an increasingly diverse, remote, and non-traditional student population. This study presents an effective model of delivering essential microbiology lab courses in a time-shortened bootcamp format that can be adapted to other STEM disciplines and has the potential to change the way lab courses are delivered to traditional students as well.

SUPPLEMENTAL MATERIALS

Appendix 1: Abbreviations
Appendix 2: Focus group participants
Appendix 3: Fulfillment of ASM curriculum guidelines
Appendix 4: Additional demographics
Appendix 5: Additional analyses of advanced microbiology lab outcomes

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